9-10 THE TYTHING, WORCESTER:
Archaeomagnetic Dating Report 2003

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Summary

Remains of a medieval tile kiln were discovered during the redevelopment of an office building in central Worcester. The find is important, as it is the first time that a medieval tile production site has been discovered within the town. The kiln was primarily constructed of tiles stacked horizontally but showed evidence of extensive repairs during its use, some of which incorporated brick into the structure. Evidence suggests that it was exclusively devoted to the production of tiles but, unfortunately, those found are not sufficiently diagnostic to precisely date the time of operation of the kiln. Archaeomagnetic analysis of the remains was therefore requested. The results show that the kiln was likely to have last been used in the mid-fifteenth century AD and that it had been remodelled some 10-15 years previously.

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Introduction

An office building, most recently used as a call centre, at 9-10 The Tything Worcester (SO 848 555, longitude 2.2°W, latitude 52.2°N) was scheduled for demolition so that the site could be redeveloped. During archaeological evaluation prior to this work, remains of a medieval tile kiln were discovered beneath the concrete floor of the building (see Figures 1 and 2, below). The kiln walls were constructed of tiles laid horizontally and stood to a height of about 1.2m. Only the south wall and parts of the east and west walls survived, the northern part of the kiln having been destroyed by more recent construction. An area of the kiln floor also remained, composed of baked clay with a north-south spine made of brick along a central section. Inspection of the surviving walls, revealed evidence of extensive repairs to the original tile structure, some incorporating bricks. The southern (external) face of the south wall had two flue arches at its base, each about 0.5m in diameter. However, these were blocked and could not have been used during the final phase of operation of the kiln. It appeared that, at some stage, the kiln had been remodelled and the walls effectively doubled in thickness by the construction of new walls abutting the inside faces of each original. On the south side, it was this new inner wall that had blocked the original flues of the kiln. Presumably new flues and fire pits were constructed to the north, in the part of the structure destroyed by subsequent construction.

Large quantities of tile were found in association with the kiln and it appears that it was exclusively devoted to their production. As such, it is an important find as, although many sites have been found in Worcester where such tiles were utilised, this is the first evidence for a production site within the town. Unfortunately, the tiles produced by the kiln are not sufficiently diagnostic to precisely date its operation within the medieval period. However, it is known that it must have ceased functioning before 1701, as an alms house was constructed on the site at this date. Given the kiln's potential importance to research into the chronology of medieval construction techniques in Worcester, Hal Dalwood of the Worcestershire Archaeological Service (WAS) requested that the English Heritage Centre for Archaeology (EH C*f*A) provide archaeomagnetic analysis of tiles from the kiln. This request was supported by the EH Inspector of Ancient Monuments for Worcestershire, Ian George.

Archaeomagnetic sampling was carried out at the site on the 12th December 2002 by the author with the assistance of members of WAS. All subsequent measurement and analysis was carried out by the author. I am grateful to Darren Miller of WAS for providing details about the site prior to the sampling visit.

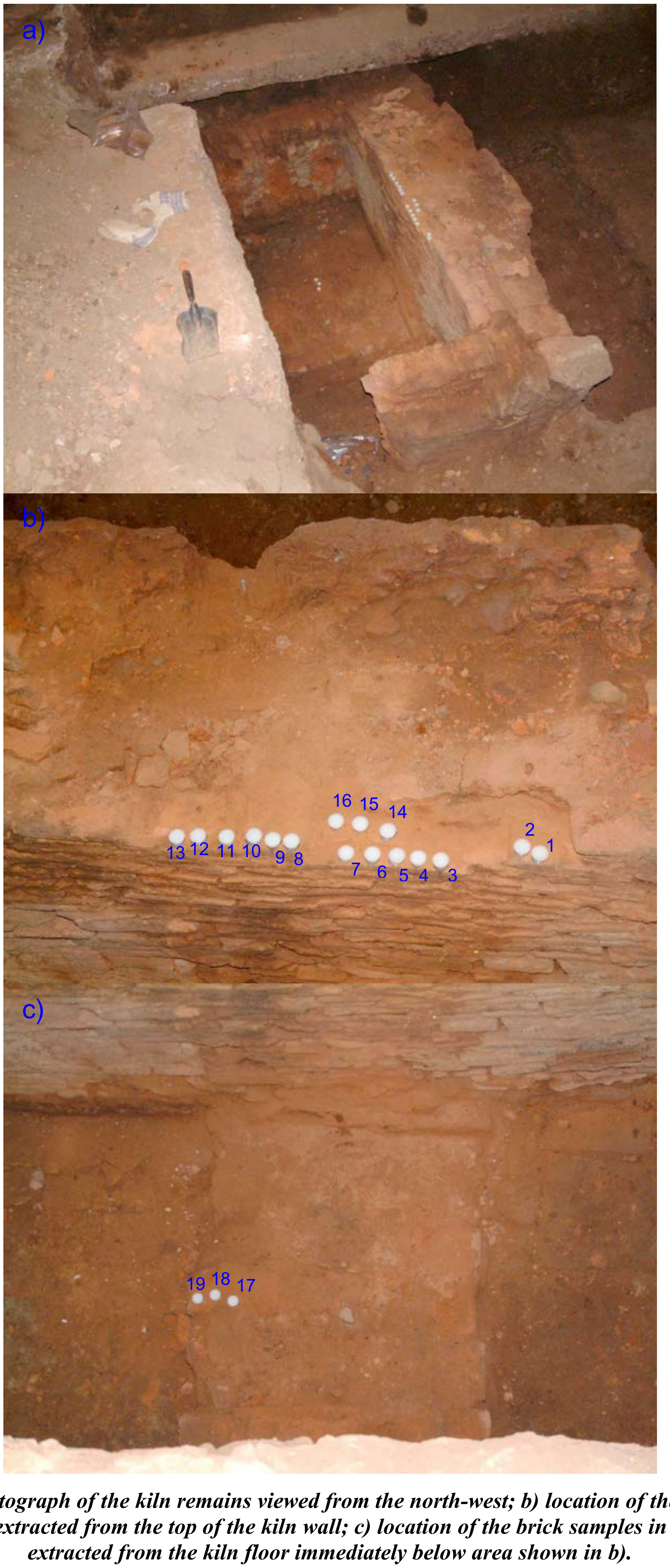

Figure 1: a) Photograph of the kiln remains viewed from the north-west; b) location of the tile samples in sample set 1TYW extracted from the top of the kiln wall; c) location of the brick samples in sample set 1TYW extracted from the kiln floor immediately below area shown in b).

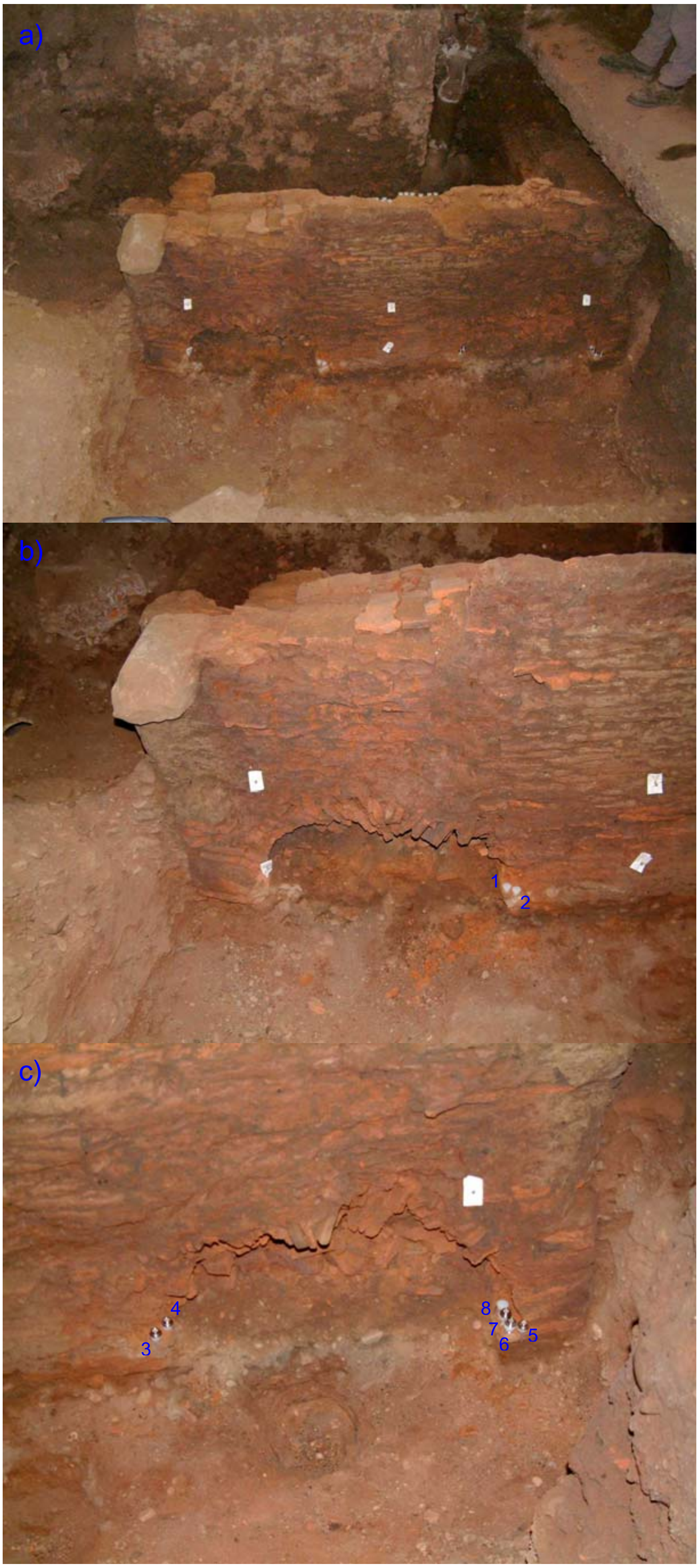

Figure 2: a) Photograph of the kiln remains viewed from the south; b) location of the samples in sample set 2TYW extracted from the left flue arch; c) location of the samples in sample set 2TYW extracted from the right kiln arch.

Method

The kiln exhibited at least two phases of use, so it was decided to collect two sets of samples to establish whether its final firing had occurred significantly later than the date at which it was remodelled and the original flue arches were blocked. The first set of samples, prefixed 1TYW, was collected from the internal (north) face of the main surviving kiln wall and from a brick in the kiln floor. These samples were intended to provide a date for the very last firing of the kiln. The second set of samples, prefixed 2TYW, was collected from tiles at the base of the blocked flue arches on the exterior (south) face of the kiln wall. These samples should date the last use of the original flues before the arches were blocked.

All samples were collected using the disc method (see appendix, section 1a). Samples 1TYW17-19 were taken from a brick in the kiln floor. All other samples were taken from the stacked tiles comprising the kiln wall (an attempt was made to sample the clay mortar between the tiles but this proved too friable, hence the omission of samples numbered 1TYW14-16). Sample set 1TYW was orientated to true north using a gyro-theodolite. During this procedure the theodolite's built-in compass was used to determine that magnetic north was 9.0° west of true north within the building. Time precluded repositioning the theodolite to get a line of sight onto sample set 2TYW, so these were orientated using a magnetic compass.

The distribution of samples in sample set 1TYW is illustrated in Figure 1 whilst the distribution for sample set 2TYW is depicted in Figure 2. In all 15 samples were recovered for set 1TYW and 9 for set 2TYW. The lower number of samples for set 2TYW was due to the difficulty of exposing horizontal tile surfaces in the flue arches to attach disks to, given the available time (see Figure 2).

In the laboratory, the extracted tiles and brick were cut into separate samples each approximately 2cm across and 1.5-2cm in depth. Sample 1TYW07 disintegrated during this procedure. However, two further sample disks, 1TYW18.1 and 1TYW18.2 were added to the brick before it was cut up. This was to allow for a better independent determination of the magnetisation direction in the brick in case it differed from that of the tile samples. An additional disk was also attached to the tile fragment containing 2TYW04 and this was given the identifier 2TYW04.1.

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 for analysing a set archaeomagnetic samples from a fired archaeological feature is to first measure their NRM magnetisation. These NRM measurements are then inspected and one or more samples are selected for pilot partial demagnetisation. Pilot demagnetisation of a sample involves exposing it to an alternating magnetic field of fixed peak strength and measuring the resulting changes in its magnetisation. The procedure is repeated with increasing peak field strengths to build up a complete picture of the coercivity spectrum of the pilot sample. From these pilot partial demagnetisation results an optimum peak field strength is selected to be applied to the remaining samples. This optimum field strength is chosen to remove as much of the secondary magnetisation as possible whilst leaving the primary magnetisation intact. The equipment used for these measurements is described in section 2 of the appendix.

A mean TRM direction is then calculated from the partially demagnetised sample measurements. 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 Tything. Comparison of the directions of magnetisation of samples from the floor and wall of the kiln suggested that no significant distortion of the local magnetic field had been caused by the magnetisation of the structure itself (see *1TYW* in Results below). Hence, no "magnetic refraction" correction was applied to the mean TRM directions before calibration (see note 3b).

Results

Feature	N	Dec°	Inc°	α_{95}	K	Date Range
1TYW all samples	17	5.9 (6.1)	59.6 (59.8)	1.2	942.1	63%: 1265 – 1285 AD or 1450 – 1470 AD 95%: 1260 – 1290 AD or 1440 – 1480 AD
1TYW tiles only	12	5.6 (5.8)	59.5 (59.7)	1.6	751.6	For comparison with brick samples' mean only.
1TYW brick only	5	6.6 (6.8)	59.9 (60.1)	1.8	1860.0	For comparison with tile samples' mean only – not strictly statistically valid as based upon fewer than 8 samples.
2TYW	8	6.1 (6.2)	59.8 (60.0)	2.2	653.3	63%: 1265 – 1290 AD or 1445 – 1480 AD 95%: 1250 – 1300 AD or 1425 – 1495 AD

Table 1; Archaeomagnetic dates inferred for the two sample sets taken from the kiln at The Tything. N = number of samples used to calculate mean TRM. Dec = mean declination (bracketed value is Meriden corrected). Inc = mean inclination (bracketed value is Meriden corrected). α_{95} = internal angle of cone of confidence. k = Fisher precision statistic.

1TYW

Sample measurements are recorded in Tables 2 to 4 and Figure 3 depicts the distribution of sample TRM directions before and after partial demagnetisation. Figures 4 to 6 illustrate the results of pilot demagnetisation on samples 1TYW08, 1TYW09 and 1TYW18.1 respectively. Pilot demagnetisation was also carried out on samples 1TYW03 and 1TYW11 (see Tables 3 and 4) but these results are not depicted graphically as their behaviour was similar to that of 1TYW09.

Table 5 shows stability estimates for the magnetisation in these samples based upon the method of Tarling and Symons (1967). 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 5 indicate that the magnetisations of all the pilot samples are extremely stable, with the maximum stabilities generally occurring between 15 and 50mT. Hence, a value of 15mT was selected to partially demagnetise the remaining samples.

The coercivity profile of sample 1TYW08 is unusual (see Figure 4). It has a large perturbation in magnetisation direction at a coercivity of 1mT, presumably caused by a viscous magnetisation component (although measurement error cannot be entirely ruled out). A secondary component is also evident in domains with coercivities between 5mT and 30mT. It is interesting that sample 1TYW09, which was taken from a location only a few centimetres away on the same tile, does not exhibit a similar profile. To exclude the effects of this secondary component, the direction of magnetisation after 50mT partial demagnetisation, rather than 15mT, was used.

The distribution of TRM directions after this treatment is depicted in Figure 3b. A mean TRM direction was calculated using these measurements (see note 3) and it is depicted in Figure 7, superimposed on the UK archaeomagnetic calibration curve. As well as calculating a mean TRM direction using all the sample measurements, two further means were calculated, the first using only the tile samples (from the wall of the kiln), the second using only the brick samples (from the kiln floor). All 3 means are listed in Table 1.

Aitken and Hawley (1971) have observed considerable differences between the magnetisation directions of samples from the floors and walls of the same kiln and concluded that this was due to the phenomenon of magnetic refraction. It has thus been standard practice to apply a magnetic refraction correction to the inclinations of measured TRM directions depending on whether they were taken from the wall or floor of a feature. However, it may be observed that the means of the wall and floor samples are not appreciably different (~1.5° of solid angle) and it was concluded that distortion of the local magnetic field had not had a significant effect on the magnetisation directions of the samples.

As a result, no magnetic refraction corrections were applied to the magnetisation directions of the samples from The Tything. After correction to Meriden, a date range for the last firing of the hearth was deduced from the mean TRM direction of all the samples (note 4):

1265 AD to 1285 AD or 1450 to 1470 at the 63% confidence level.
1260 AD to 1290 AD or 1440 to 1480 at the 95% confidence level.

Unfortunately the mean TRM direction corresponds to a virtual geomagnetic pole position that occurred twice during the medieval period so two separate date ranges have to be given.

2TYW

This sample set was taken from the edges of tiles facing onto the flue arches in the south face of the surviving kiln wall (see Figure 2). It is possible that heat from later firings of the kiln might have radiated through the kiln walls, partially remagnetising these tiles. However, the remodelled wall was some 30cm thick, providing quite a degree of thermal insulation, and it was expected that the desired magnetisation direction would still be retained, in the higher coercivity domains at least.

Sample measurements are recorded in Tables 6 and 7 and Figure 8 depicts the distribution of sample TRM directions before and after partial demagnetisation. Figures 9 and 10 illustrate the results of pilot demagnetisation on samples 2TYW01 and 2TYW03 respectively. Table 5 shows stability estimates for the magnetisation in these two samples based upon the method of Tarling and Symons (1967). 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 5 indicate that the magnetisations of both pilot samples are extremely stable, with the maximum stabilities generally occurring in the range between 15 and 30mT. Hence, a value of 15mT was selected to partially demagnetise the remaining samples.

The distribution of TRM directions after this treatment is depicted in Figure 8b. The declination of the TRM direction of sample 2TYW03 is still anomalously high even after 15mT partial demagnetisation. As its magnetisation was stable, it was concluded that this was due to problems orientating the sample on site (space around the sample disks was extremely constricted and it was difficult to correctly align the compass when marking the sample disks). Thus, sample 2TYW03 was excluded from the measurement set and a mean TRM direction was calculated using the remaining 8 measurements (see note 3). This mean is quoted in Table 1 and is depicted in Figure 11, superimposed on the UK archaeomagnetic calibration curve. The archaeomagnetic date range deduced from it is:

1265 AD to 1290 AD or 1445 to 1480 at the 63% confidence level.
1250 AD to 1300 AD or 1425 to 1495 at the 95% confidence level.

This date range is similar to that for feature 1TYW although less precise as it is based upon fewer samples (8 as opposed to 17). The test of McFadden and Lowes (1981) shows that there is a 97.0% probability that the mean TRM directions calculated for sample sets 1TYW and 2TYW are both estimates of the same underlying direction. It is thus likely that sample set 2TYW dates either the same firing event as 1TYW or an event less than 10-15 years earlier (events occurring this close together cannot be distinguished with present archaeomagnetic techniques).

Conclusions

Archaeomagnetic analysis of the two sets of samples from 9-10 The Tything, Worcester has successfully determined mean TRM directions of good precision for both, that for 1TYW being particularly precise. Unfortunately these mean directions both correspond to a virtual geomagnetic pole (VGP) position that occurred twice during the medieval period, and, for each mean, two different date ranges are possible.

In the case of sample set 1TYW the resolution of this ambiguity is perhaps straightforward. Samples 1TYW17-19 were of brick and the incorporation of brick into even high status structures was rare in Worcestershire until the C16th AD (H. Dalwood *pers. comm.*). These samples came from the firing chamber of the kiln so they will date its last firing. A last use in the C13th AD would be far too early for brick to be present in the structure. Hence, the later date range of 1440 to 1480 AD (at 95% confidence) is almost certain to be correct.

For the case of sample set 2TYW, which would be expected to date the last use of the original flues of the kiln before they were blocked, the argument is more involved. There are 3 possibilities:

i) Enough heat radiated through the wall of the kiln during firings after the original flues were blocked to allow the magnetic domains in these tile samples to realign. Hence they also record the field direction at the time the kiln was last fired. Given that the remodelled wall was some 30-35cm thick, it seems likely that tile edges on its outer side would be well insulated from the heat. It is thus likely that the field direction acquired just before the original flues were blocked would survive as a primary component in higher coercivity domains at least. The later field direction would thus be expected to manifest itself as a secondary component in only the lower coercivity domains. No secondary component was observed in the two samples on which pilot partial demagnetisation was performed, so it seems likely that the magnetisation direction recorded in sample set 2TYW is indeed that acquired at the time the original flues were last used.

ii) The original flues were last used in the later part of the C13th AD (corresponding to the earlier date range) and, after remodelling, the kiln continued in use until the mid C15th AD. This prospect seems extremely unlikely. It would entail the kiln being used for more than 200 years. Furthermore, for the last use of the original flues to occur at exactly the time the VGP first occupied the position Dec = 6.5°, Inc = 59.7° and the final firing of the kiln to occur exactly at the second time would be fortuitous in the extreme.

iii) The final use of the original flues occurred less than 10-15 years before the kiln was last fired. In this case the two TRM direction would be archaeomagnetically indistinguishable, given the present level of development of the technique. In the light of the forgoing this seems by far the most likely of the possibilities.

Thus it may be concluded that the tile kiln discovered at 9-10 The Tything, Worcester was last fired some time between 1440 and 1480 AD, having been remodelled and the original flue arches blocked some 10-15 years previously.

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Archaeomagnetic Date Summary

Archaeomagnetic ID:	**1TYW**
Feature:	**9-10 The Tything, Worcester**
Location:	**Longitude 2.2^{o}W, Latitude 52.2^{o}N**
Number of Samples (taken/used in mean):	**17/17**
AF Demagnetisation Applied:	**15mT (50mT for 1TYW08)**
Distortion Correction Applied:	**0^{o}**
Declination (at Meriden):	**5.9^{o} (6.1^{o})**
Inclination (at Meriden):	**59.6^{o} (59.8^{o})**
Alpha-95:	**1.2^{o}**
k:	**942.1**
Date range (63% confidence):	**1265 AD to 1285 AD or 1450 AD to 1470 AD**
Date range (95% confidence):	**1260 AD to 1290 AD or 1440 AD to 1480 AD**
Independent date estimate:	**Medieval, earlier than 1701 AD**

Archaeomagnetic ID:	**2TYW**
Feature:	**9-10 The Tything, Worcester**
Location:	**Longitude 2.2^{o}W, Latitude 52.2^{o}N**
Number of Samples (taken/used in mean):	**9/8**
AF Demagnetisation Applied:	**15mT**
Distortion Correction Applied:	**0^{o}**
Declination (at Meriden):	**6.1^{o} (6.2^{o})**
Inclination (at Meriden):	**59.8^{o} (60.0^{o})**
Alpha-95:	**2.2^{o}**
k:	**653.3**
Date range (63% confidence):	**1265 AD to 1290 AD or 1445 AD to 1480 AD**
Date range (95% confidence):	**1250 AD to 1300 AD or 1425 AD to 1495 AD**
Independent date estimate:	**Medieval, earlier than 1701 AD**

Sample	NRM Measurements				After Partial Demagnetisation				
	Material	Dec°	Inc°	J(mAm⁻¹)	AF(mT)	Dec°	Inc°	J(mAm⁻¹)	R
1TYW01	Tile	8.0	61.3	5081.9	15.0	8.7	59.9	2942.7	
1TYW02	Tile	6.6	61.2	4236.1	15.0	7.5	60.1	2496.8	
1TYW03	Tile	7.3	60.6	2365.6	15.0	6.6	59.4	1031.6	
1TYW04	Tile	6.9	64.4	1769.8	15.0	4.0	63.3	791.9	
1TYW05	Tile	8.6	63.0	1322.5	15.0	7.4	62.0	733.1	
1TYW06	Tile	10.2	62.3	1015.8	15.0	9.5	61.9	571.9	
1TYW08	Tile	22.5	64.4	334.3	50.0	5.7	59.2	94.7	
1TYW09	Tile	1.5	61.7	707.0	15.0	2.2	61.1	376.9	
1TYW10	Tile	1.2	62.1	1066.3	15.0	0.6	58.7	614.5	
1TYW11	Tile	6.3	55.2	743.1	15.0	8.1	54.1	435.2	
1TYW12	Tile	3.9	59.5	3603.9	15.0	3.5	57.5	1941.1	
1TYW13	Tile	7.1	58.7	5324.1	15.0	4.0	56.2	2433.1	
1TYW17	Brick	5.5	61.8	187.9	15.0	6.0	60.6	128.3	
1TYW18	Brick	6.4	60.2	186.2	15.0	7.1	58.4	120.3	
1TYW18.1	Brick	12.6	61.1	1906.6	15.0	11.8	60.3	1211.7	
1TYW18.2	Brick	2.7	61.1	839.0	15.0	3.0	60.4	547.0	
1TYW19	Brick	4.2	62.5	705.4	15.0	5.0	59.4	391.1	

Table 2: NRM measurements of samples and measurements after partial AF demagnetisation for feature 1TYW. J = magnitude of magnetisation vector; AF = peak alternating field strength of demagnetising field; R = sample rejected from mean calculation.

AF(mT)	1TYW03			1TYW08			1TYW09		
	Dec°	Inc°	J(mAm⁻¹)	Dec°	Inc°	J(mAm⁻¹)	Dec°	Inc°	J(mAm⁻¹)
0.0	-0.8	60.5	2310.7	23.8	63.7	327.5	2.6	62.4	694.0
1.0	-0.6	60.2	2253.3	14.8	59.6	319.1	2.8	61.5	663.7
2.5	-0.2	60.9	2174.1	24.1	63.7	299.2	3.2	60.8	618.3
5.0	-0.0	60.5	1897.4	26.1	63.7	277.5	3.5	60.4	555.6
7.5	-0.4	60.1	1594.7	26.8	63.2	252.6	2.1	61.6	486.5
10.0	-0.6	59.8	1344.0	25.7	63.3	231.2	1.9	61.5	448.9
15.0	-0.3	59.4	1031.6	20.2	62.4	196.2	2.2	61.1	376.9
20.0	-0.7	59.7	847.7	15.3	61.3	170.1	1.8	61.1	334.5
30.0	0.6	59.7	676.5	9.2	60.4	139.2	1.9	60.6	283.5
50.0	1.6	60.5	524.0	5.9	59.6	111.7	1.7	60.7	230.1
75.0	1.5	60.9	438.8	5.7	59.2	94.7	3.3	61.0	197.4
100.0	0.5	60.1	391.1	4.5	58.8	86.0	2.3	60.7	179.0

Table 3: Incremental partial demagnetisation measurements for samples 1TYW03, 1TYW08 and 1TYW09.

AF(mT)	1TYW11			1TYW18.1		
	Dec°	Inc°	J(mAm^{-1})	Dec°	Inc°	J(mAm^{-1})
0.0	9.4	55.1	724.1	10.4	60.7	1859.8
1.0	8.9	54.4	693.9	11.1	60.6	1840.5
2.5	8.5	54.3	659.4	10.8	60.5	1786.5
5.0	8.6	54.1	604.5	11.0	60.4	1667.9
7.5	8.8	53.9	553.9	11.0	60.4	1537.5
10.0	8.2	54.0	501.0	11.4	60.4	1407.4
15.0	8.1	54.1	435.2	11.8	60.3	1211.7
20.0	7.9	54.5	393.0	11.7	60.2	1091.9
30.0	7.2	54.3	345.4	10.8	60.2	950.2
50.0	8.2	53.8	293.6	10.6	60.4	804.0
75.0	7.2	54.1	260.3	11.8	59.5	733.1
100.0	7.2	54.3	242.7	11.0	59.9	673.2

Table 4: Incremental partial demagnetisation measurements for samples 1TYW11 and 1TYW18.1.

Sample	Range min. (mT)	Range max. (mT)	Max. Stability	Dec°	Inc°
1TYW03	0.0	100.0	49.9	0.0	60.2
1TYW08	50.0	100.0	40.1	5.4	59.2
1TYW09	15.0	100.0	80.3	2.2	60.9
1TYW11	10.0	100.0	81.5	7.7	54.2
1TYW18.1	1.0	50.0	91.0	11.1	60.4

Table 5: Assessment of the range of demagnetisation values over which each sample attained its maximum directional stability for feature 1TYW, 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.

Sample	NRM Measurements				After Partial Demagnetisation				
	Material	Dec°	Inc°	J(mAm^{-1})	AF(mT)	Dec°	Inc°	J(mAm^{-1})	R
2TYW01	Tile	5.9	60.8	19708.9	15.0	5.2	60.1	10033.5	R
2TYW02	Tile	14.5	63.3	20679.0	15.0	14.6	61.2	10346.1	
2TYW03	Tile	22.8	61.1	14970.1	15.0	23.0	60.7	7270.8	R
2TYW04	Tile	5.6	59.2	8640.5	15.0	4.5	58.8	3768.8	
2TYW04.1	Tile	8.8	56.4	9410.5	15.0	8.5	54.9	4317.4	
2TYW05	Tile	19.8	67.9	2877.6	15.0	0.9	59.8	495.0	
2TYW06	Tile	5.4	63.3	4642.9	15.0	1.3	59.4	1127.8	
2TYW07	Tile	9.5	62.9	3601.4	15.0	8.2	61.2	560.9	
2TYW08	Tile	5.6	61.9	3396.2	15.0	5.5	62.5	461.0	

Table 6: NRM measurements of samples and measurements after partial AF demagnetisation for feature 2TYW. J = magnitude of magnetisation vector; AF = peak alternating field strength of demagnetising field; R = sample rejected from mean calculation.

AF(mT)	2TYW01	2TYW03

	Dec°	Inc°	J(mAm^{-1})	Dec°	Inc°	J(mAm^{-1})
0.0	6.2	60.3	20025.2	19.1	60.7	14992.1
1.0	5.6	60.2	19860.5	21.6	61.6	14935.0
2.5	4.1	60.2	19361.7	22.6	61.3	14517.3
5.0	5.5	60.1	18314.8	23.2	61.3	13278.2
10.0	7.2	59.8	14633.9	22.9	60.9	9916.2
15.0	5.2	60.1	10033.5	23.0	60.7	7270.8
20.0	5.2	59.9	7307.6	23.2	60.8	5770.8
30.0	8.8	59.7	4344.3	23.2	60.8	4218.5
50.0	2.5	60.1	2852.3	22.9	60.2	3412.1
75.0	7.6	59.9	2405.2	22.0	59.7	3099.8

Table 7: Incremental partial demagnetisation measurements for samples 2TYW01 and 2TYW03.

Sample	Range min. (mT)	Range max. (mT)	Max. Stability	Dec°	Inc°
2TYW01	0.0	75.0	29.8	5.8	60.0
2TYW03	15.0	30.0	151.8	23.1	60.8

Table 8: Assessment of the range of demagnetisation values over which each sample attained its maximum directional stability for feature 2TYW, 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 α_{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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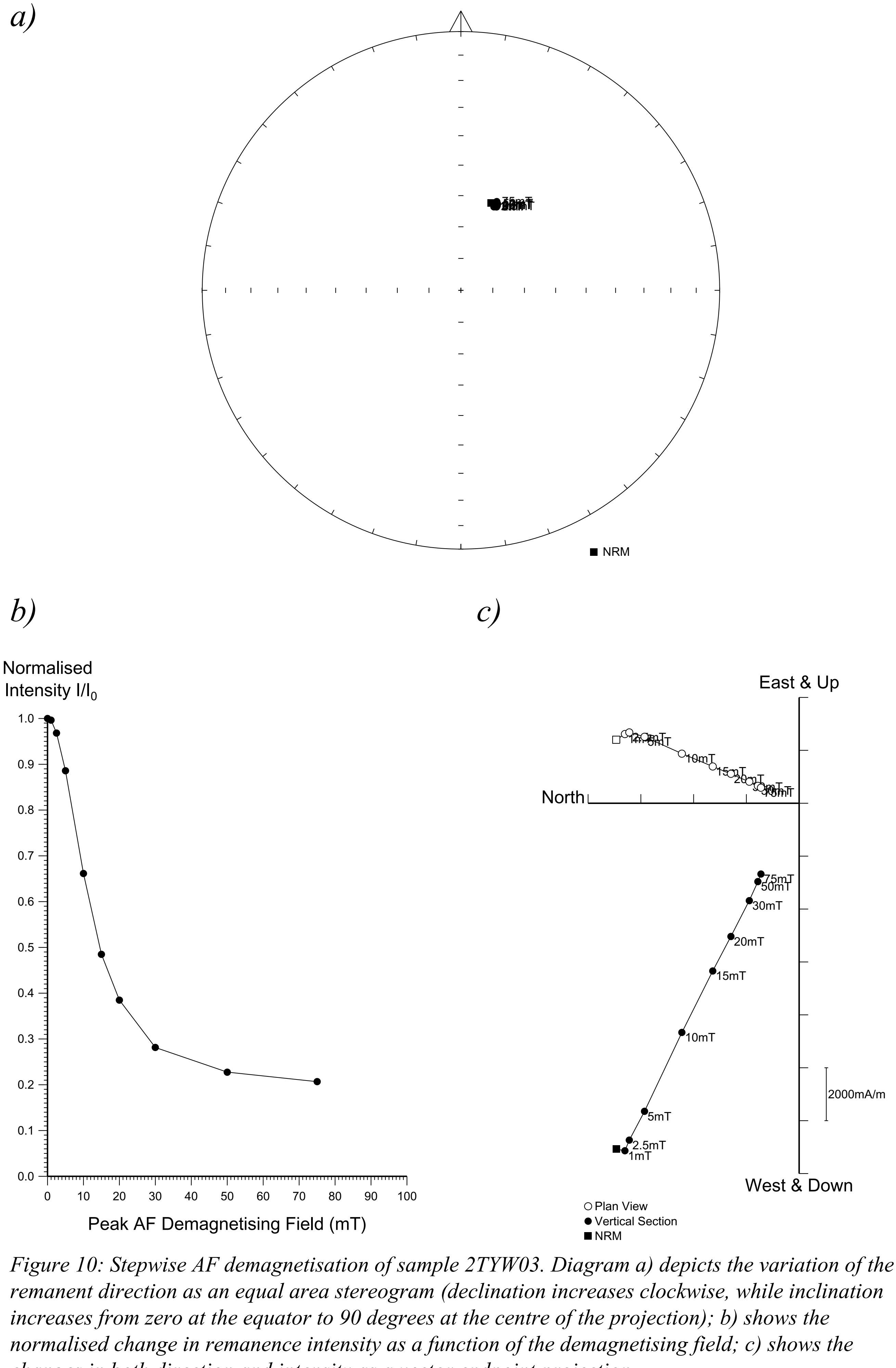
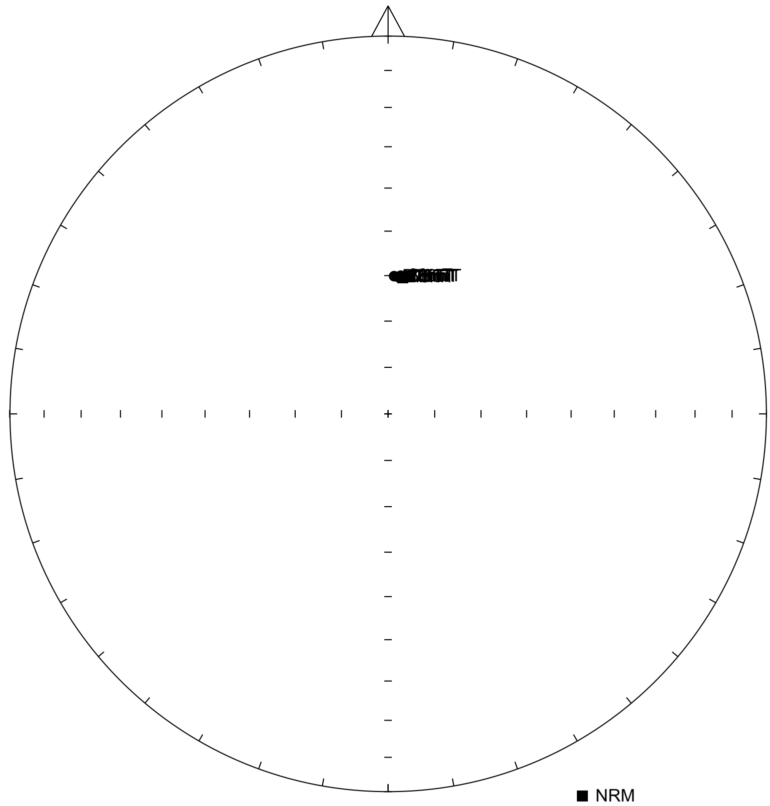
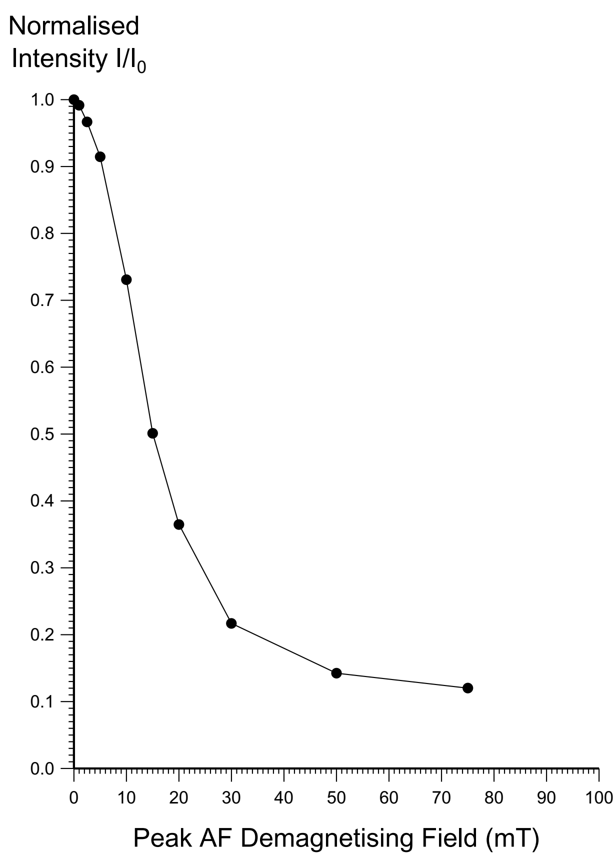


Figure 10: Stepwise AF demagnetisation of sample 2TYW03. Diagram a) depicts the variation of the remanent direction as an equal area stereogram (declination increases clockwise, while inclination increases from zero at the equator to 90 degrees at the centre of the projection); b) shows the normalised 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)



c)

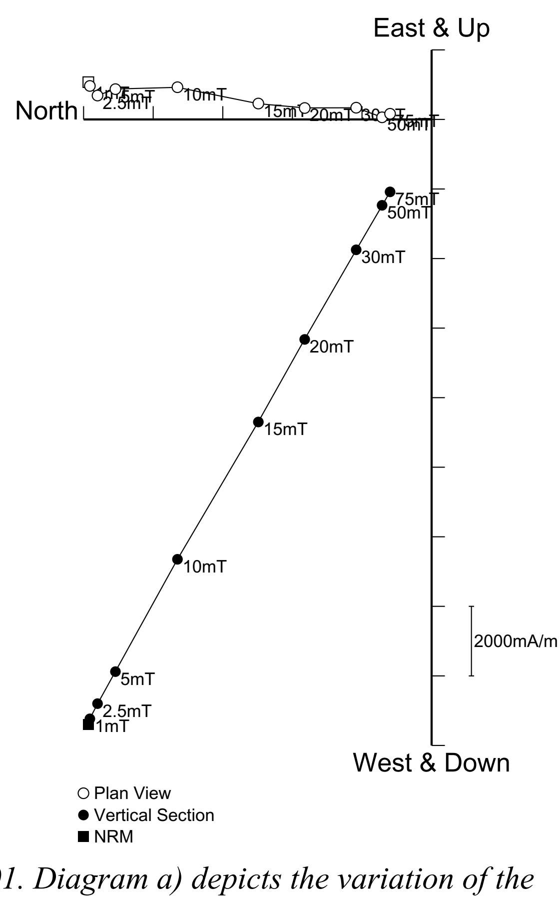


Figure 9: Stepwise AF demagnetisation of sample 2TYW01. Diagram a) depicts the variation of the remanent direction as an equal area stereogram (declination increases clockwise, while inclination increases from zero at the equator to 90 degrees at the centre of the projection); b) shows the normalised 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.

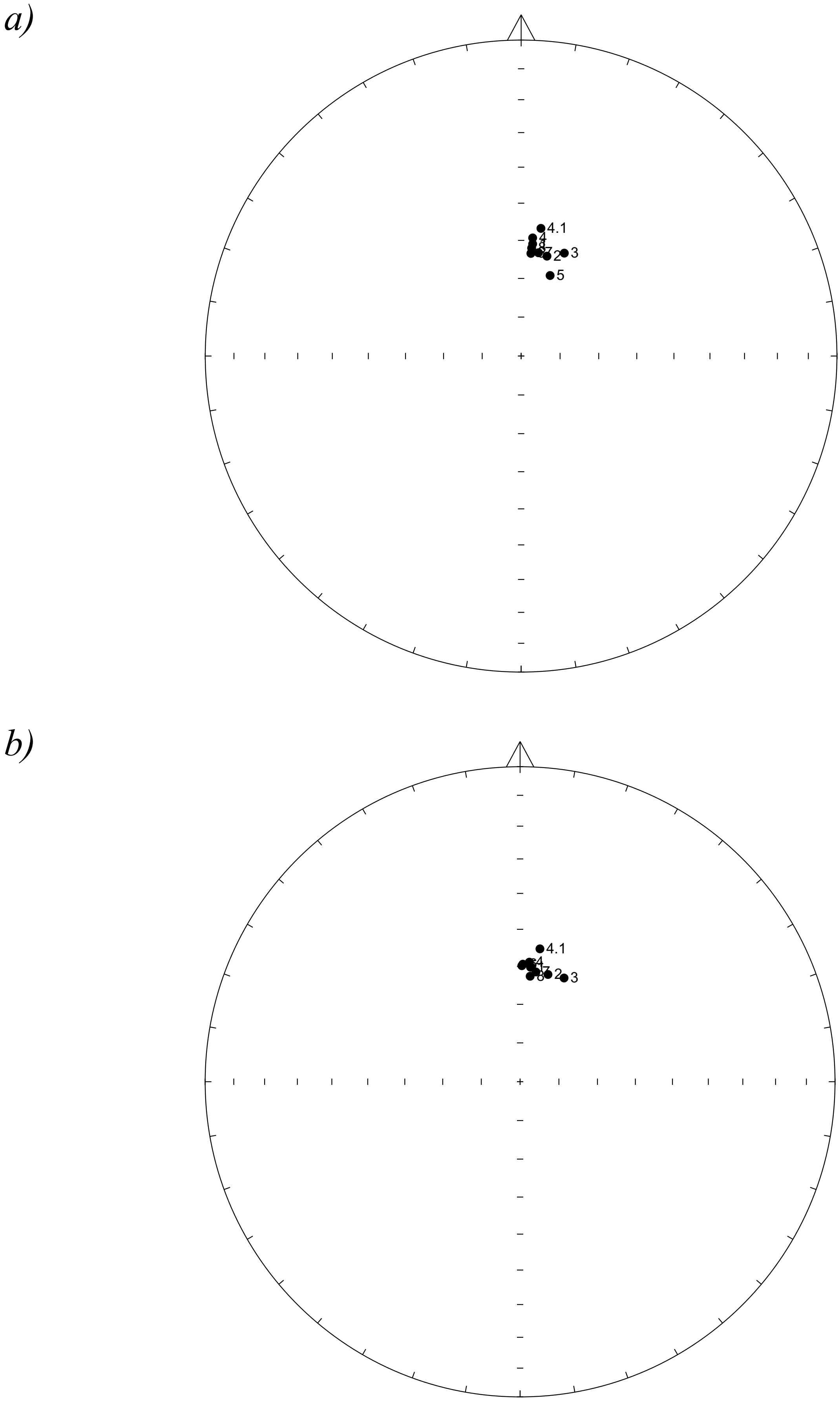


Figure 8: a) Distribution of NRM directions of samples from feature 2TYW represented as an equal area stereogram. In this projection declination increases clockwise with zero being at 12 o'clock while inclination increases from zero at the equator to 90 degrees in the centre of the projection. Open circles represent negative inclinations. b) Distribution of thermoremanent directions of magnetisation of the same samples after partial AF demagnetisation to 15mT.

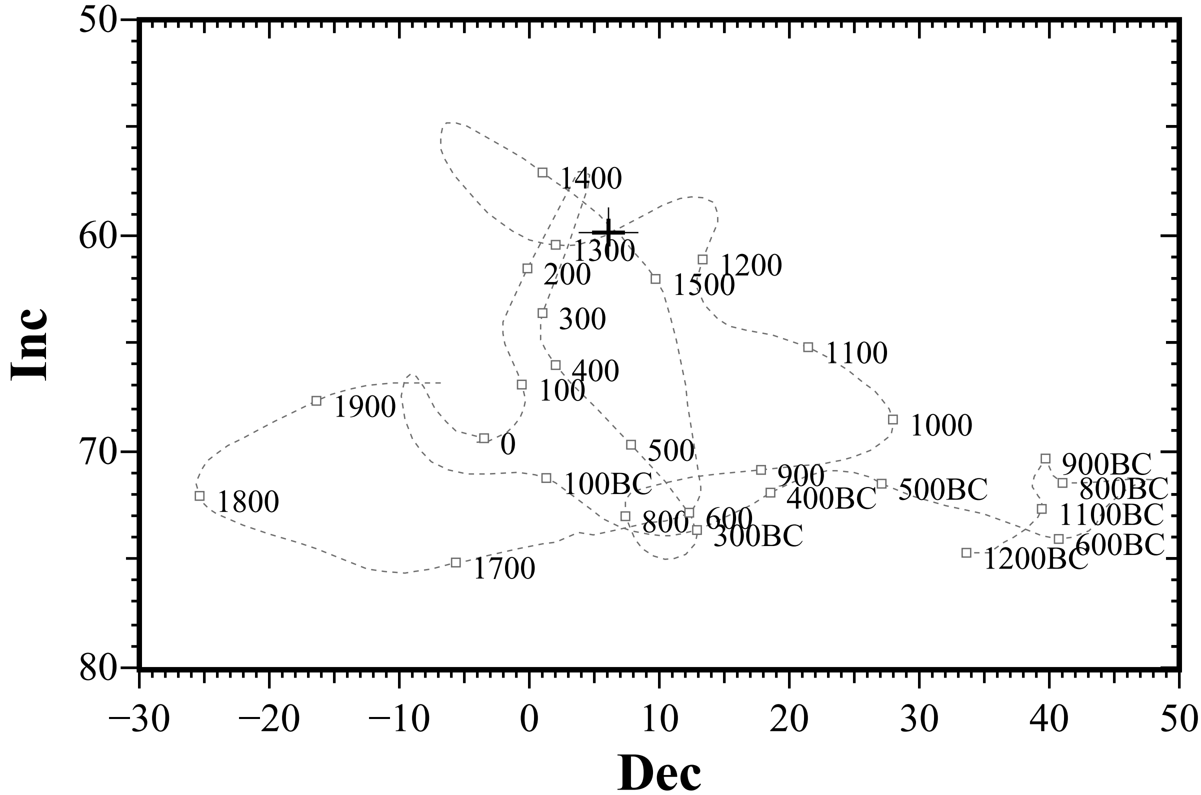


Figure 7: Comparison of the mean thermoremanent vector calculated from samples 01-06, 08-13, 17-18, 18.1, 18.2 and 19 from feature 1TYW after 15mT/50mT partial demagnetisation with the UK master calibration curve. Thick error bar lines represent 63% confidence limits and narrow lines 95% confidence limits.

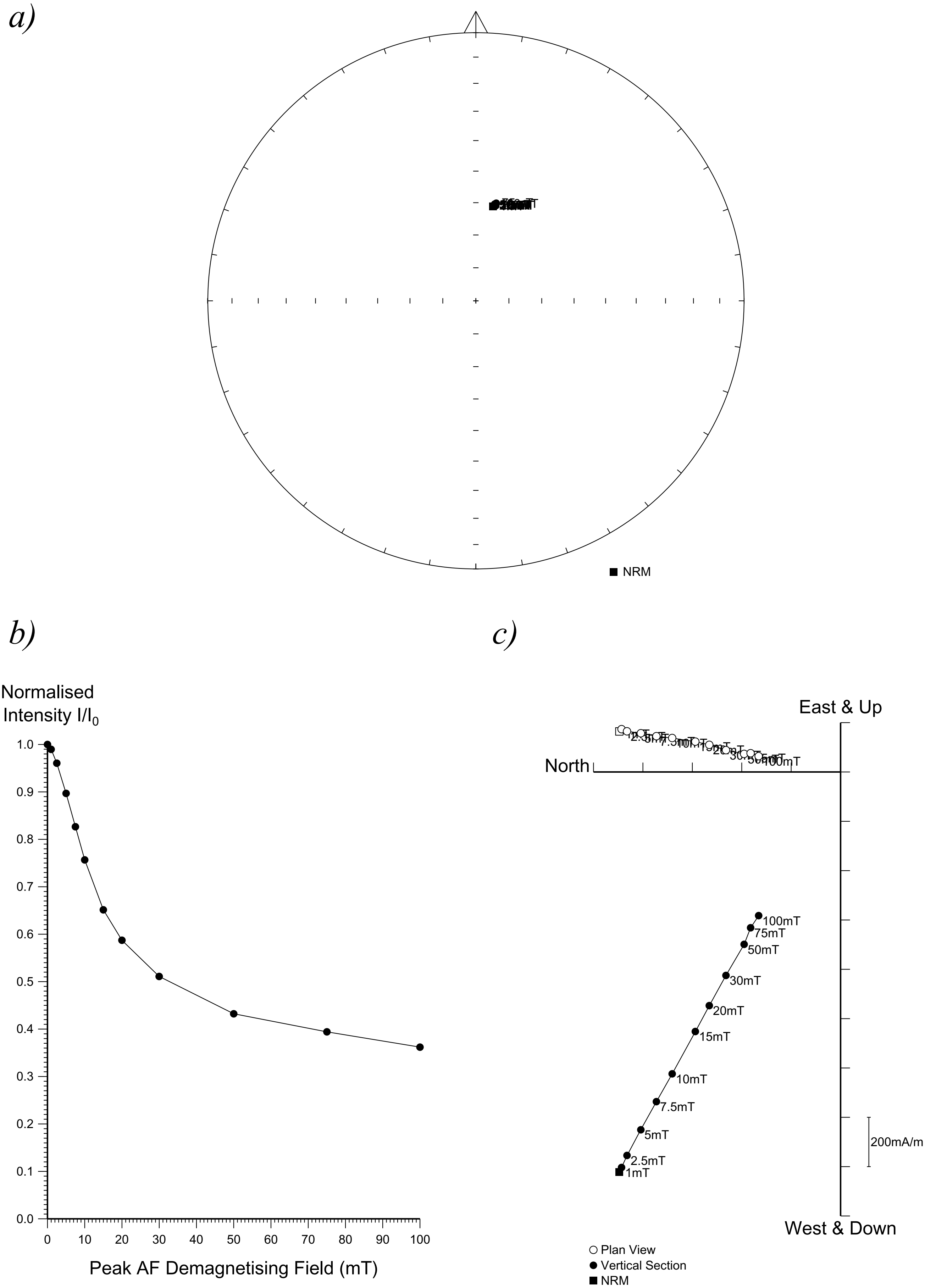
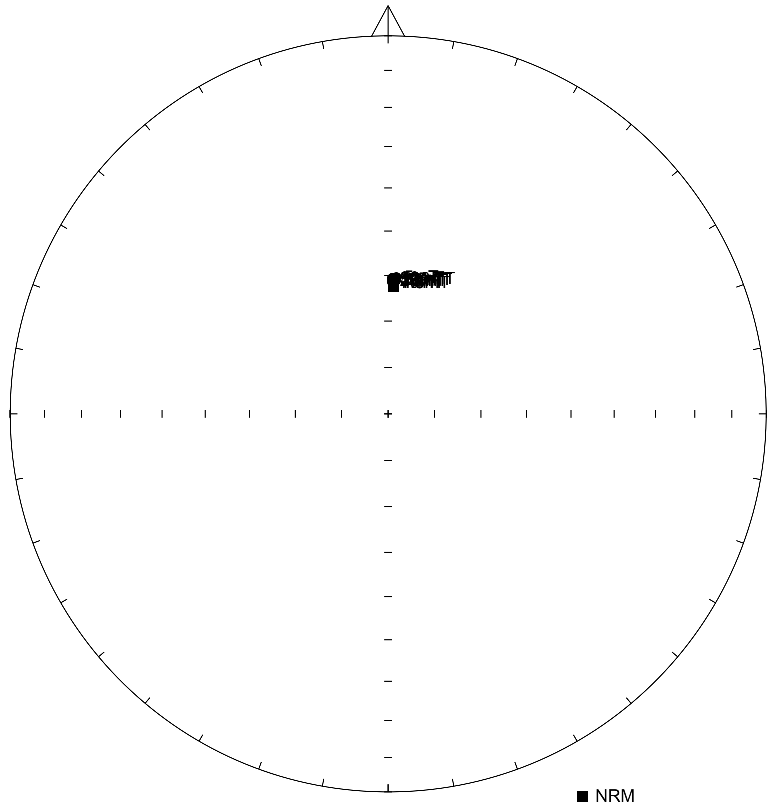
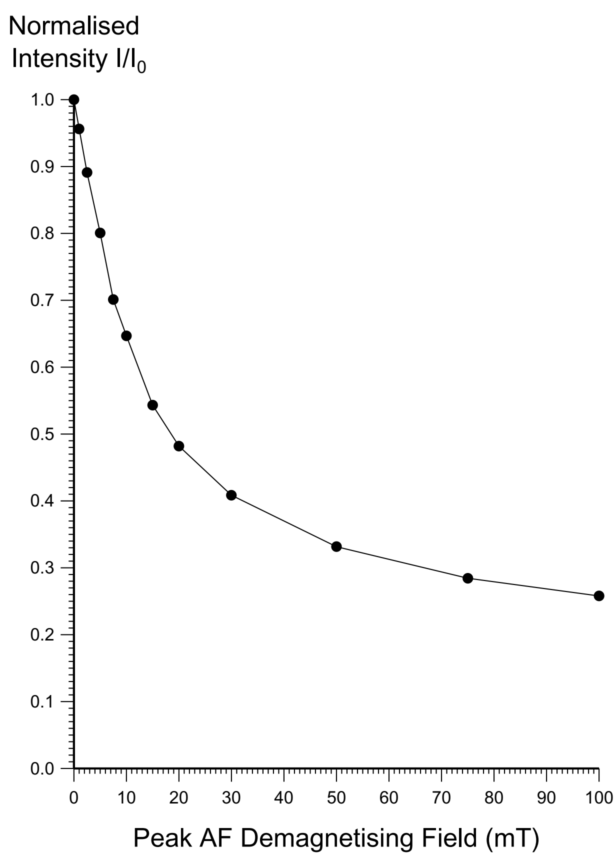


Figure 6: Stepwise AF demagnetisation of sample 1TYW18.1. Diagram a) depicts the variation of the remanent direction as an equal area stereogram (declination increases clockwise, while inclination increases from zero at the equator to 90 degrees at the centre of the projection); b) shows the normalised 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)



c)

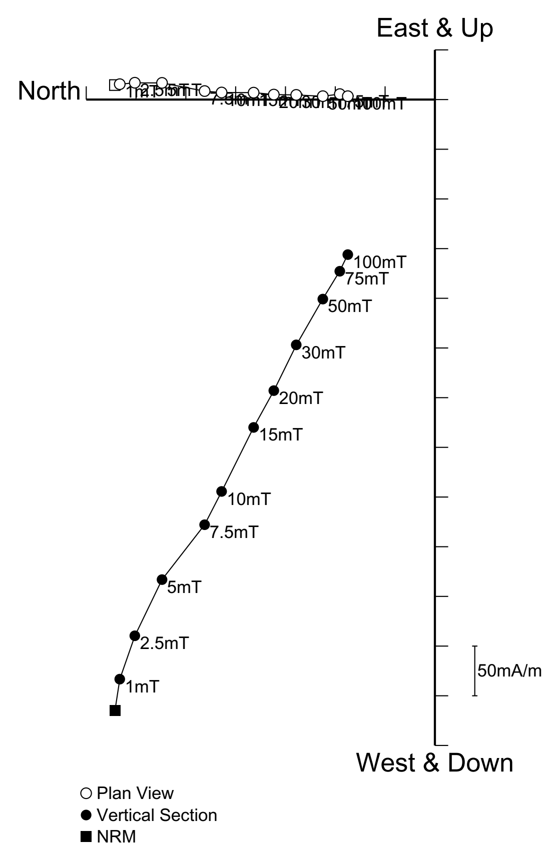


Figure 5: Stepwise AF demagnetisation of sample 1TYW09. Diagram a) depicts the variation of the remanent direction as an equal area stereogram (declination increases clockwise, while inclination increases from zero at the equator to 90 degrees at the centre of the projection); b) shows the normalised 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.

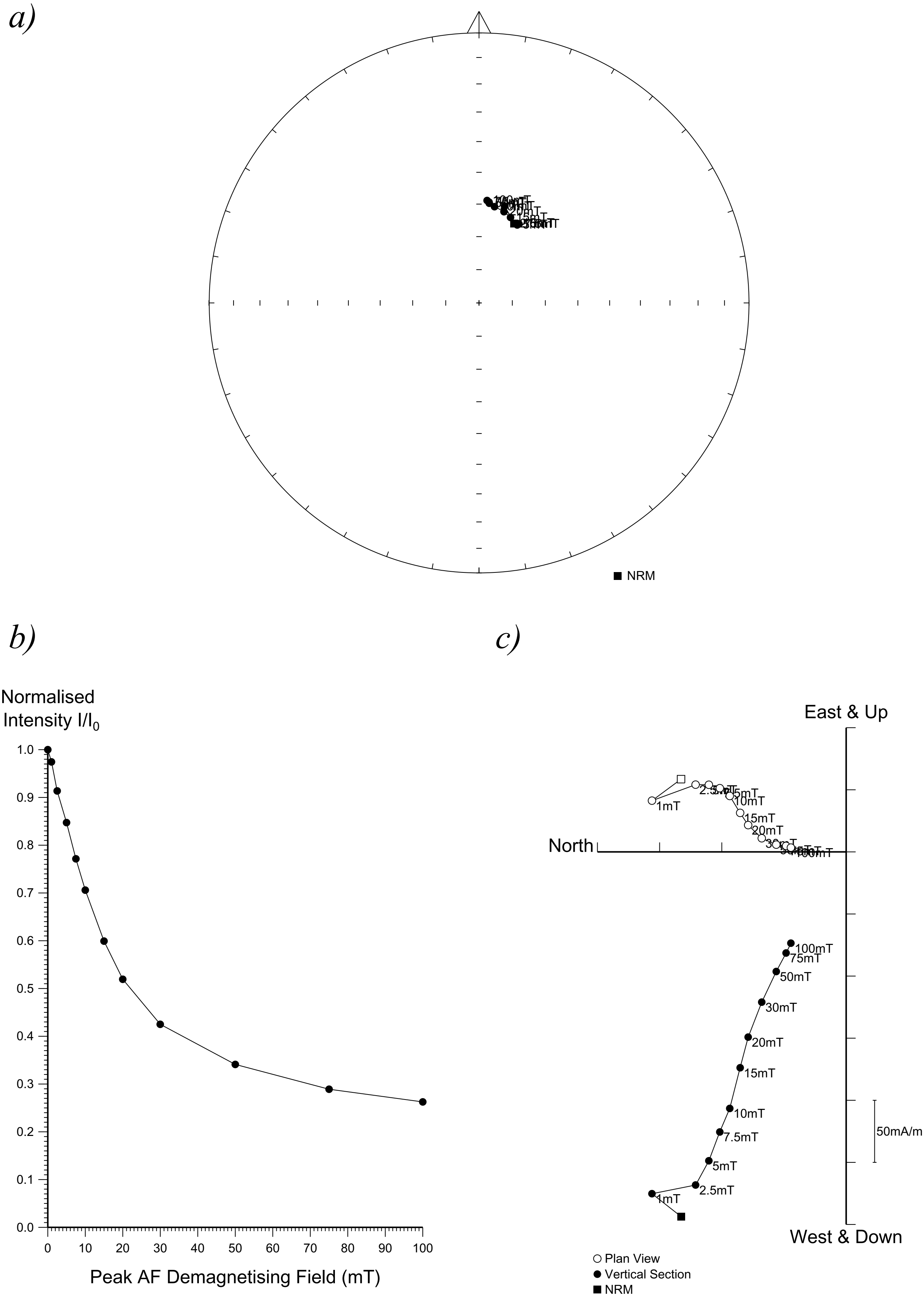
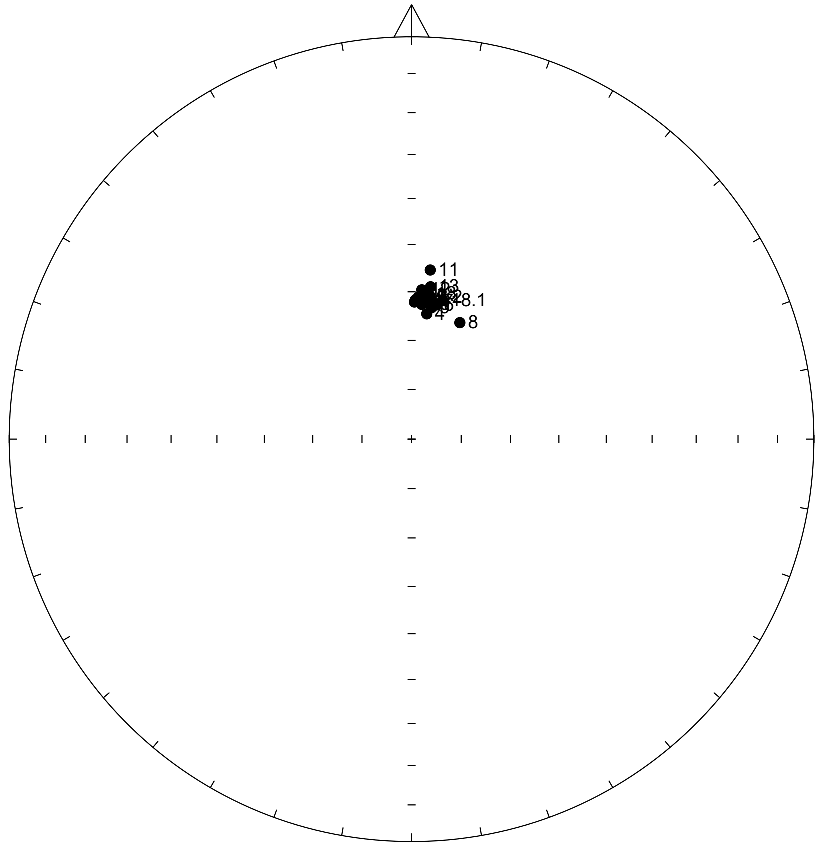


Figure 4: Stepwise AF demagnetisation of sample 1TYW08. Diagram a) depicts the variation of the remanent direction as an equal area stereogram (declination increases clockwise, while inclination increases from zero at the equator to 90 degrees at the centre of the projection); b) shows the normalised 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)

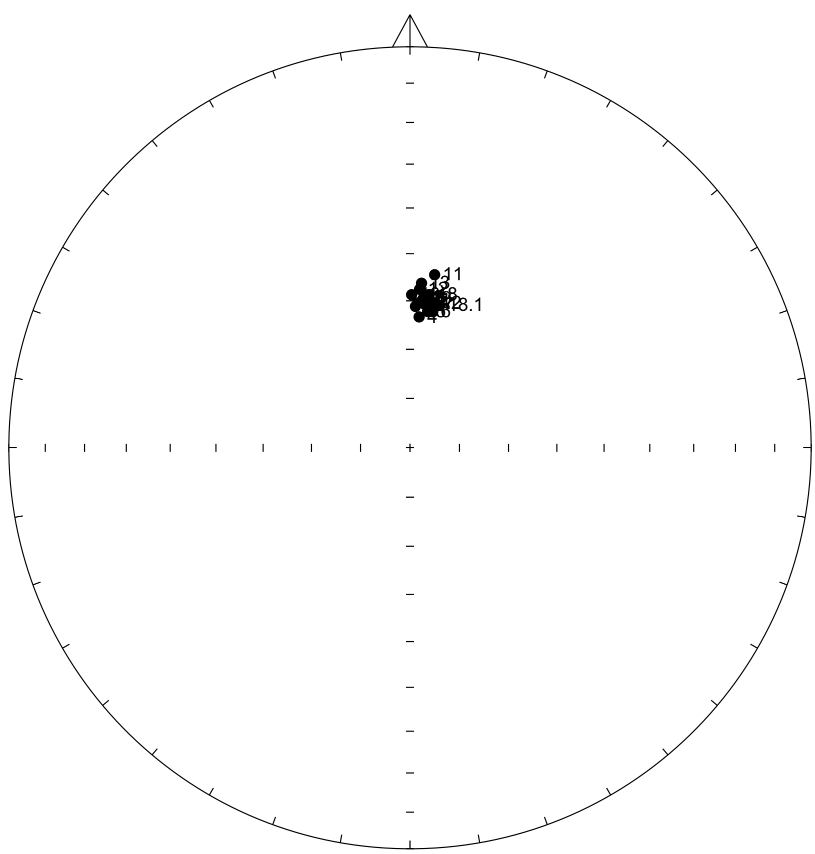


Figure 3: a) Distribution of NRM directions of samples from feature 1TYW represented as an equal area stereogram. In this projection declination increases clockwise with zero being at 12 o'clock while inclination increases from zero at the equator to 90 degrees in the centre of the projection. Open circles represent negative inclinations. b) Distribution of thermoremanent directions of magnetisation of the same samples after partial AF demagnetisation to 15mT (50mT in the case of 1TYW08).

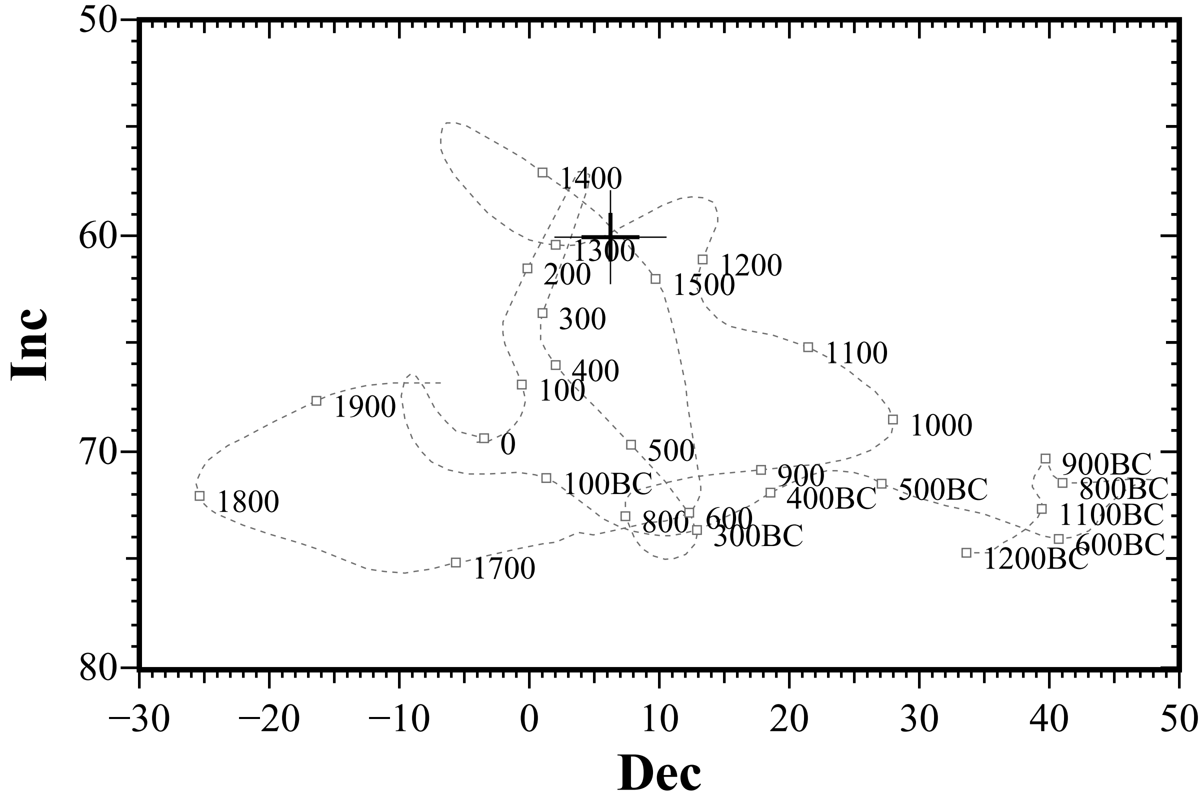


Figure 11: Comparison of the mean thermoremanent vector calculated from samples 01-02, 04, 04.1 and 05-08 from feature 2TYW after 15mT partial demagnetisation with the UK master calibration curve. Thick error bar lines represent 63% confidence limits and narrow lines 95% confidence limits.