NOAK HILL, HAVERING, Essex:
Archaeomagnetic Dating Report 2001

Introduction

Archaeological investigations carried out by the Rochford Hundred Archaeological Society in the garden of Weald View in Noak Hill near Harold Wood and Havering in Essex in 1997 uncovered the well preserved remains of a medieval kiln (TQ 534 940, Latitude 51.6^{o}N, Longitude 0.2^{o}E). The kiln was rectangular and constructed of stacked tiles mortared together with fired clay (Figure 1). Other finds from the site indicated that the area was associated with the production of Mill Green ware which was manufactured in the region during the 13th and 14th centuries AD. However, it was not clear whether the excavated kiln was used to produce this pottery. The English Heritage Ancient Monuments Laboratory (EH AML) was requested to sample the feature for archaeomagnetic dating by the regional Inspector of Ancient Monuments, Ellen Barnes. Sampling was carried out on the 28th July and 2nd August 1997 by the author and subsequent measurement and evaluation was performed by the author and Louise Martin of the English Heritage Centre for Archaeology (EH CfA).

Figure 1; The Noak Hill kiln during excavation of its southeast quadrant. Photograph taken from the east.

Method

Samples were collected using the disc method (see appendix, section 1a) and orientated to true north using a gyro-theodolite. A total of 49 samples were recovered over the two visits, NK01-24 on the first visit and NK201-225 on the second visit. However, NK212 and NK214 proved to be too small to measure. The provenance of the samples was as follows:

NK01-12	Orange clay above kiln flue.
NK13-17	Red clay mortar between tiles on east wall of kiln.
NK18-24	Orange/red clay mortar between tiles on east wall, south of the above group.
NK201-204	Tile from the south wall.
NK205-211	Orange/red clay mortar from south wall.
NK212-221	Orange/red clay mortar from east wall.
NK222-225	Tile from east wall.

All the laboratory measurements were made using the equipment described in section 2 of the appendix.

Results

The natural remanent magnetisation (NRM) measurements for all samples are listed in Table 1 and the distribution of their directions is depicted in Figure 2a. Most of the samples are quite strongly magnetised and their directions form three distinct clusters. The exceptions are samples NK01-12 from the clay above the kiln flue. These have highly anomalous, widely scattered, NRM directions as depicted in Figure 2b.

The NRM of the samples is assumed to be caused by thermoremanent magnetisation (TRM) at the time that the feature 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.

In the case of tile samples, it is also possible that a TRM is retained relating to the time when the tile itself was manufactured. If the tile was subjected to a very high temperature during its manufacture then all its magnetic domains, even those with high coercivities, would be realigned. However, when it was later incorporated into the kiln wall, it is possible that it was not exposed to such a high temperature. Thus, only the lower coercivity domains would realign with the new field direction. In this case the total magnetisation of the tile would consist of two components, one, relating to the time it was manufactured, preserved in the high coercivity domains, the other, relating to the last firing of the kiln, preserved in the lower coercivity domains.

Hence four samples, NK07 (clay), NK18 (clay), NK203 (tile) and NK222 (tile), were demagnetised incrementally to a peak alternating field of 96mT and the changes in their remanence recorded to identify the components of their magnetisation. The measurements are tabulated in Tables 2 and 3 and depicted graphically in Figures 3-6. The magnetisation in sample NK07 (Figure 3) is clearly unstable with a strong viscous component at low coercivities and no consistent magnetisation direction at higher coercivities. It was thus concluded that samples NK01-12 had not been exposed to sufficient heat to attain a stable magnetisation during the operation of the kiln. These samples were thus excluded from further analysis.

The magnetisation in the other three samples (Figures 4-6) appears stable, with no secondary component apparent at higher coercivities in the two tile samples. However, a small component of viscous remanence has been detected at low coercivities in all three persisting up to the 4mT demagnetisation increment. It was thus decided to partially demagnetise the remaining samples in an 8mT AF field to remove this viscous component[1]. The distribution of sample TRMs after this treatment is depicted in Figure 7a; the measured values are listed in Table 1.

It can be seen in Figure 7a, that the sample TRM directions form three distinct clusters which relate to the parts of the kiln structure they derived from. Figure 7b plots the mean TRM directions of the samples from each cluster, corresponding to the kiln's south and east walls, and the part of the east wall above the arch where the flue entered the kiln. In each case an ellipse representing the associated α_{95} confidence limit is also shown (note 3c). It can be seen that whilst each mean is individually quite precise, they are all statistically distinct and the means from the south wall and the east wall above the flue arch both have very shallow inclinations.

Whilst some shape dependent distortion of the TRM direction can be caused by so called "magnetic refraction" effects (note 3b), this generally accounts for deviations of only 2-3^{o}. Inspection of the kiln and the samples taken from it suggests that the more likely explanation for the shallow inclinations is slumping of the structure since it was last fired. It is possible to estimate bedding corrections (Tarling 1983, p83) to correct for the effects of slumping by examining the disposition of the kiln walls and assuming that they were originally vertical. However, the errors involved in these estimates introduce an additional degree of uncertainty into the final calculated mean TRM direction. In this case, applying bedding corrections was considered unnecessary as there were sufficient good samples from parts of the east wall that had been unaffected by slumping. Hence, the samples from the south wall and that part of the east wall above the flue arch were excluded from the final mean TRM calculation.

The mean TRM direction of the remaining 17 samples, NK13-17 and NK212-225, was calculated (see note 3) to be:

At site:Dec = -1.4^{o} Inc = 55.3^{o} α_{95} = 2.2^{o} k = 264.4
At Meriden: Dec = -2.1^{o} Inc = 56.2^{o}

This mean is depicted in relation to the UK archaeomagnetic dating curve in Figure 8 and it can be seen that it coincides with the segment of the calibration curve for the 14th Century AD, giving date ranges for the last firing of the kiln of:

1375 to 1395 cal AD at the 63% confidence level.

[1]It should be noted that sample NK223 was initially used as a pilot demagnetisation sample. However, owing to equipment failure, its incremental partial demagnetisation values were not measured correctly, so the TRM after the final 24mT demagnetisation step has been used.

1365 to 1405 cal AD at the 95% confidence level.

Conclusions

Archaeomagnetic analysis of the samples from Noak Hill has established that the kiln excavated there was last fired towards the end of the14th Century AD. Although many samples had to be rejected from the final calculation, the mean TRM of the remaining 17 was of good precision and the inferred date range approaches the tightest that can be achieved using the present UK calibration information (note 4). During the analysis it was discovered that the clay above the flue, although reddened, had not been exposed to sufficiently high temperatures for it to remagnetise. It was also found that the south wall of the kiln and the part of the east wall above the flue arch had slumped since the kiln was last fired.

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Archaeomagnetic Date Summary

Site:	**Noak Hill, Harold Wood, Havering**
Location:	**Longitude 0.2E, Latitude 51.6N**
Number of Samples (taken/used in mean):	**49/17**
AF Demagnetisation Applied:	**8mT**
Distortion Correction Applied:	**None**
Bedding Correction Applied:	**None**
Mean Declination at Site:	**-1.4^{o}**
Mean Inclination at Site:	**55.3^{o}**
Mean Declination at Meriden:	**-2.1^{o}**
Mean Inclination at Meriden:	**56.2^{o}**
Alpha-95:	**2.2^{o}**
k:	**264.4**
Date range (63% confidence):	**1375 to 1395 cal AD**
Date range (95% confidence):	**1365 to 1405 cal AD**

	NRM Measurements				After Partial Demagnetisation			
Sample	Material	Dec°	Inc°	J(mA/m)	AF(mT)	Dec°	Inc°	J(mA/m)
NK01	Clay	69.7	4.5	376.5	8	-	-	-
NK02	Clay	-19.3	56.2	771.6	8	-	-	-
NK03	Clay	25.3	61.3	272.8	8	-	-	-
NK04	Clay	13.0	60.7	534.5	8	-	-	-
NK05	Clay	-20.4	19.6	836.2	8	-	-	-
NK06	Clay	19.8	5.6	46.7	8	-	-	-
NK07	Clay	9.8	66.3	107.7	8	-	-	-
NK08	Clay	-33.4	32.3	84.9	8	-	-	-
NK09	Clay	30.3	61.8	64.7	8	-	-	-
NK10	Clay	-14.7	72.6	71.4	8	-	-	-
NK11	Clay	111.6	38.4	1012.2	8	-	-	-
NK12	Clay	14.7	-41.6	3368.9	8	-	-	-
NK13	Clay	1.6	52.8	3621.1	8	-0.9	51.0	2541.8
NK14	Clay	5.8	52.7	2419.7	8	5.5	51.7	1459.7
NK15	Clay	-6.0	62.4	1772.3	8	-5.2	60.6	1276.4
NK16	Clay	-2.9	63.4	922.9	8	-5.1	61.3	666.1
NK17	Clay	-8.0	57.6	2029.7	8	-8.6	57.8	1407.0
NK18	Clay	-1.7	47.6	288.8	8	-6.4	47.0	228.1
NK19	Clay	0.3	46.5	399.4	8	-1.9	45.4	318.4
NK20	Clay	-4.2	42.4	809.4	8	-5.0	41.7	648.0
NK21	Clay	-2.4	40.0	3706.8	8	-4.7	38.4	2841.8
NK22	Clay	-9.9	46.8	7694.7	8	-8.0	45.6	5151.2
NK23	Clay	1.2	43.7	852.0	8	-0.8	42.5	667.5
NK24	Clay	-5.9	45.1	481.7	8	-5.5	43.6	395.3
NK201	Tile	4.2	32.4	2150.2	8	3.4	31.3	1844.9
NK202	Tile	7.1	34.1	718.2	8	5.0	31.6	589.4
NK203	Tile	4.9	35.7	1129.2	8	3.3	33.6	915.4
NK204	Tile	7.8	35.9	1735.5	8	7.1	35.3	1421.5
NK205	Clay	10.1	31.2	16627.5	8	9.0	29.5	14470.8
NK206	Clay	2.5	30.4	8144.0	8	4.1	31.1	7301.5
NK207	Clay	1.7	23.6	10882.4	8	3.9	24.0	8906.0
NK208	Clay	0.1	24.2	13354.6	8	0.4	22.6	10492.4
NK209	Clay	2.9	27.8	13898.2	8	3.6	26.0	10692.5
NK210	Clay	3.1	23.9	6447.5	8	2.9	23.4	5345.2
NK211	Clay	4.7	24.8	6824.5	8	4.8	23.8	5431.4
NK213	Clay	4.3	54.8	7434.7	8	1.0	51.6	3900.7
NK215	Clay	-3.6	53.1	3936.2	8	-5.4	48.5	2400.9
NK216	Clay	1.9	55.6	1232.7	8	-0.8	51.6	873.4
NK217	Clay	-7.4	54.2	6453.7	8	-7.0	53.6	4337.8
NK218	Clay	12.2	52.7	4424.0	8	13.2	52.0	2460.7
NK219	Clay	-3.5	57.7	10559.6	8	-7.6	56.0	5350.4
NK220	Clay	2.1	55.7	7152.1	8	-1.6	54.2	3571.9
NK221	Clay	3.6	60.3	2168.0	8	-1.6	55.8	1127.3
NK222	Tile	10.0	57.3	222.4	8	6.3	56.9	177.6
NK223	Tile	5.6	60.2	191.3	24	-1.6	59.5	89.4
NK224	Tile	0.2	57.5	214.3	8	-5.2	58.4	173.6
NK225	Tile	5.1	59.1	129.7	8	-2.4	58.1	105.0

Table 1: Sample NRM measurements and measurements after partial demagnetisation. J = magnitude of magnetisation vector; AF = peak alternating field strength of demagnetising field.

	NK07			NK18		
AF(mT)	Dec°	Inc°	J(mA/m)	Dec°	Inc°	J(mA/m)
0	-13.9	60.8	87.7	-9.3	48.6	294.0
1	-12.2	61.2	95.9	-9.3	48.5	286.6
2	-11.4	59.6	87.6	-8.4	48.2	283.6
4	-5.2	60.9	66.4	-8.2	47.5	272.5
8	-1.5	60.8	45.7	-6.4	47.0	228.1
12	11.6	58.6	22.2	-5.5	46.1	174.9
16	3.1	35.0	9.7	-5.5	46.5	131.2
24	-61.0	74.6	1.2	-4.8	46.2	93.8
32	24.6	10.7	1.2	-7.1	44.8	79.7
48	-91.6	18.0	9.3	-4.1	47.0	65.4
64	117.4	-54.9	3.6	-4.3	49.2	60.9
96	-	-	-	-5.4	48.3	54.5

Table 2: Incremental partial demagnetisation measurements for samples NK07 and NK18.

	NK203			NK222		
AF(mT)	Dec°	Inc°	J(mA/m)	Dec°	Inc°	J(mA/m)
0	1.7	34.3	1141.8	6.2	59.2	219.6
1	2.7	34.5	1127.7	6.8	58.5	216.3
2	1.7	33.9	1118.0	6.2	58.1	215.6
4	2.9	34.1	1073.6	6.3	57.3	204.8
8	3.3	33.6	915.4	6.3	56.9	177.6
12	3.4	33.1	690.2	5.5	56.9	151.5
16	2.3	32.5	507.7	4.8	57.0	133.3
24	1.1	32.7	322.1	-	-	-
32	7.5	31.9	286.6	3.7	56.9	105.5
48	3.4	31.4	253.4	-	-	-
64	4.3	32.5	232.6	3.5	56.1	87.4
96	4.2	31.6	195.6	3.5	56.1	78.9

Table 3: Incremental partial demagnetisation measurements for samples NK203 and NK222.

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).

References

Aitken, M. J. 1990. *Science-based Dating in Archaeology*. London: Longman.

Aitken, M. J. and H. N. Hawley 1971. Archaeomagnetism: evidence for magnetic refraction in kiln structures. *Archaeometry* **13**, 83-85.

As, J. A. 1967. The a.c. demagnetisation technique, in *Methods in Palaeomagnetism*, D. W. Collinson, K. M. Creer and S. K. Runcorn (eds). Amsterdam: Elsevier.

Clark, A. J., D. H. Tarling and M. Noel 1988. Developments in Archaeomagnetic Dating in Britain. *J. Arch. Sci.* **15**, 645-667.

Creer, K. M. 1959. A.C. demagnetisation of unstable Triassic Keuper Marls from S. W. England. *Geophys. J. R. Astr. Soc.* **2**, 261-275.

Fisher, R. A. 1953. Dispersion on a sphere. *Proc. R. Soc. London A* **217**, 295-305.

Molyneux, L., R. Thompson, F. Oldfield and M. E. McCallan 1972. Rapid measurement of the remanent magnetisation of long cores of sediment. *Nature* **237**, 42-43.

Mook, W. G. 1986. Recommendations/Resolutions Adopted by the Twelfth International Radiocarbon Conference. *Radiocarbon* **28**, M. Stuiver and S. Kra (eds), 799.

Tarling, D. H. 1983. *Palaeomagnetism*. London: Chapman and Hall.

Thompson, R. and F. Oldfield 1986. *Environmental Magnetism*. London: Allen and Unwin.

Turner, G. M. and R. Thompson 1982. Detransformation of the British geomagnetic secular variation record for Holocene times. *Geophys. J. R. Astr. Soc.* **70**, 789-792.