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LITTLE FURNACE WOOD, MAYFIELD, EAST SUSSEX
ARCHAEOMAGNETIC ANALYSIS OF THREE IRON-WORKING FEATURES

SCIENTIFIC DATING REPORT

Mark Noel

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ARCHAEOMAGNETIC ANALYSIS OF THREE IRON-WORKING FEATURES

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SUMMARY

Forty-seven samples of fired material were removed from Contexts [3], [98], and [135] for the purpose of archaeomagnetic analysis and dating. Specimens were oriented *in situ* using the button method, combined with spirit levels and a north-seeking gyro compass. Some of the material was rather friable, and as a result a number of samples disintegrated during transport and cutting. Demagnetisation tests showed that the magnetisation in the material is stable. The mean archaeomagnetic vectors in each context were compared with the UK Master Curve to suggest that last firing occurred in the date ranges AD 40–60 (furnace [3]), and AD 60–220 or AD 270–480 (furnace [135]). Archaeomagnetic vectors in ore-roasting hearth [98] were too poorly grouped to form the basis for a reliable magnetic date. The date ranges obtained are consistent with radiocarbon results in the case of furnace [135], but rather earlier than the radiocarbon date associated with furnace [3]. This radiocarbon date, however, appears to provide only a *terminus ante quem* for the final firing of furnace [3].

CONTRIBUTORS

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ARCHIVE LOCATION

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DATE OF INVESTIGATION

2007–10

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INTRODUCTION

Remains of a Romano-British bloomery furnace at Little Furnace Wood were discovered by members of the Wealden Iron Research Group in September 2003. The site, between Heathfield and Mayfield, in East Sussex (NGR TQ591245; Fig 1), is one of over 120 known from the period in the Sussex and Kent Weald. The site is in light woodland, on a level area above the valley side, about 150m from the public road. Iron slag is scattered over more than 2000m^2 on the side of a small valley formed by a minor tributary of the River Rother. A combined excavation by the Wealden Iron Research Group and the Mid-Sussex Field Archaeology team has revealed the survival of significant parts of two bloomery smelting furnaces, one built into an oblong depression set into a hillside, the other built over a shallow surface depression, and two ore-roasting areas nearby.

The first furnace sampled, Context [3], was roughly circular in shape, with an internal diameter of about 0.8m, and survives to a height of about 1m (Fig 2). Evidence of the slagged lining of the inner sides suggests that the height was originally somewhat greater, with a chimney (diameter *c* 0.6m) formerly extending above the dome. Its size makes this furnace larger than others found in the Weald and similar in size to furnaces of contemporary, or slightly earlier date, found at Laxton, Northamptonshire (Jackson *et al* 1998) and at Clérimois, Yonne, France (Dunikowski and Cabboi 1995). A stone revetment has been revealed on either side of, or downhill from, the furnace. Also, a forging hearth has been uncovered in front of the furnace, based on sandstone slabs inclined into a shallow basin.

The second furnace sampled, Context [135], lies approximately 25m west of Context [3], and is of smaller design, which may indicate a different date. Occupying an area of about 1m^2, it is constructed of a cylindrical shaft, possibly above a low dome, and a shallow depression beneath (Fig 3).

About 70m uphill of the remains of furnace Context [135], the remains of two ore-roasting hearths have been excavated; the more complete of the two, Context [98], measures 4×3m, and is considerably larger than others found on contemporary sites (Fig 4). Several charred logs were found in the bottom of the hearth, which probably survive from when the hearth was last used. This hearth was also sampled.

Archaeomagnetic dating was commissioned by English Heritage, which also funded the dating of a radiocarbon sample from the 2007 excavation season. Earlier radiocarbon measurements were funded by the Wealden Iron Research Group.

Figure 1: location of Little Furnace Wood, near Mayfield, East Sussex

Figure 2. Furnace [3] (J Hodgkinson)

Figure 3. Furnace [135] (J Hodgkinson)

Figure 4. Ore-roasting hearth [98] (C Butler)

PRINCIPLES OF MAGNETIC DATING

Magnetic dating is based on comparing the remanent magnetisation in an archaeological structure with a calibrated reference curve for the geomagnetic secular variation. Two distinct methods have evolved. The intensity technique relies on obtaining estimates of the past strength of the Earth's magnetic field while directional magnetic dating uses archaeomagnetic measurements to derive the orientation of the geomagnetic vector in antiquity. Intensity dating can only be applied to fired materials which have acquired a thermoremanent magnetisation upon cooling from high temperatures (>600º C) while the directional method enables the age of a broader range of archaeological materials to be determined. For example, sediments and soils may have acquired a dateable 'detrital remanence' if magnetic grains had been aligned by the ambient field during deposition. The growth of magnetic minerals during diagenesis or as a result of manufacturing processes can also give rise to a magnetisation which may enable materials such as iron-rich mortars, for example, to be dated. However hearths, kilns and other fired structures are the most common features selected for magnetic dating primarily because their thermoremanence is generally strong, stable and sufficiently homogeneous that the ancient field can be determined with sufficient precision from a small set of specimens. An analysis of dated archaeomagnetic directions, largely from fired structures, together with lake sediment and observatory records has enabled a master curve for the UK region to be synthesised for the period 2000 BC to the present (Clark *et al* 1988).

For directional magnetic dating it is essential to obtain specimens of undisturbed archaeological material whose orientation with respect to a geographic coordinate frame is known. A number of sampling strategies have evolved, enabling specimens to be recovered from a range of archaeological materials with orientations being recorded relative to topographic features, the direction of the sun, magnetic or geographic north. Modern archaeomagnetic magnetometers are sufficiently sensitive that only small volumes of material (~1mL) are required for an accurate remanence measurement (Molyneux 1971). This has the advantage of reducing the impact of sampling on archaeological features – of particular significance if they are scheduled for conservation and display. For dating, all archaeomagnetic vectors are transposed to Meriden, the reference location for the UK Master Curve (Noel and Batt 1990).

FIELDWORK

Archaeomagnetic sampling was undertaken by the Museum of London Archaeology Geomatics Team, in December 2007. The miniaturised 'button method' was employed (Clark *et al* 1988; English Heritage 2006) with orientation by north-seeking gyro compass (Fig 5).

Figure 5. Button sampling of Furnace [3] (Museum of London Archaeology)

During the work the temperature on site was between 1 and 3 degrees Celsius, which presented problems with the epoxy resin used to consolidate the samples. The hardening time was considerably longer than usual and meant that samples had to be constantly relevelled. Context [135] was the most problematic and samples 14 and 15 fell off before they could be marked. Additional buttons were then placed on this context, and all remaining samples survived being marked and lifted (Fig 6).

Figure 6. Button sampling of Furnace [135] (Museum of London Archaeology)

Context [98] was the least promising feature for archaeomagnetic sampling. Although it appeared to be *in-situ*, there was a certain amount of bioturbation, which made it less stable. After some discussion, and following the successful sampling of the two furnaces, it was decided to go ahead and sample the most stable, burnt-looking material visible in context [98] (Fig 7).

Figure 7. Button sampling of ore-roasting hearth [98] (Museum of London Archaeology)

ANALYTICAL METHODS

Archaeomagnetic remanence was measured using a Molspin fluxgate spinner magnetometer, and stability was assessed using stepwise, alternating field demagnetisation. Secondary components of magnetisation were removed by partial demagnetisation. The mean of selected vectors was computed (with unit weights) and corrected to Meriden. Comparison then made to the UK Master Curve to obtain a last-firing date. Vectors for [3] were consistently well-grouped enough to justify including all in the mean calculation. Sample 7 was a clear outlier, however, having a declination that is geomagnetically impossible at this latitude, and hence it was justifiably excluded from the mean calculation.

RESULTS

Sample measurements and context means are given in Tables 1–3. The estimated date range for last firing of Context [98] is found to be AD 40–60 (68% confidence). The estimated date range for last firing of Context [135] is found to be AD 60–220 or AD 270–480 (68% confidence). The archaeomagnetic vectors in this context are poorly grouped (both due to the small size of the sample set and the large dispersion within that small group) and the error envelope overlaps with two separate sections of the UK Master Curve, resulting in the ambiguity in dates given here. However, assuming either choice of date, this context appears to be later than sample Context [3]. The archaeomagnetic vectors in Context [98] are very poorly grouped (probably due to either post-firing disturbance, weathering, or inadequate firing), hence the context is undatable.

Table 1: results of archaeomagnetic analyses, Context [3]

SAMPLE	J	D	I	AF	D	I
1	186.5	5.5	67.1	2.5	9.4	67.3
3	12.0	9.7	70.5	2.5	14.8	70.0
4	185.5	359.8	66.1	2.5	359.3	65.9
5	771.2	4.6	70.6	2.5	6.0	70.0
6	323.6	1.1	70.0	2.5	5.3	68.8
7	214.3	2.6	69.3	2.5	7.0	69.3
9	1171.7	358.6	68.9	2.5	1.5	69.0
10	883.7	354.0	67.3	2.5	356.8	68.3
11	154.9	353.7	66.8	2.5	352.5	65.5
12	706.8	3.3	69.1	2.5	3.1	69.6
13	968.8	0.8	69.1	2.5	2.1	69.4
14	114.6	0.7	70.1	2.5	2.2	69.2
15	459.8	354.9	69.8	2.5	354.0	70.2
MEAN K = 892.1; alpha95 = 1.46; c.s.e. = 0.8		2.5	68.8			
MERIDEN		2.6	69.7			

Key: J = intensity (mAm^{-1}x10^{-2}); D = declination; I = inclination; AF = peak alternating demagnetising field (milliTesla); K = precision parameter; c.s.e. = circular standard error; alpha95 = semi-angle of the 95% cone of confidence. Samples 2 and 8 disintegrated during cutting and have not been measured. The second set of D and I values are after A.F. demagnetisation in a field of 2.5mT.

Table 2: results of archaeomagnetic analyses, Context [135]

SAMPLE	J	D	I	AF	D	I	Comment
7	160.0	75.6	72.4	2.5	76.1	72.5	reject (see text)
11	177.7	14.2	66.1	2.5	13.0	67.5	
12	66.7	12.8	62.1	2.5	11.8	61.9	
16	2368.2	2.2	74.3	2.5	357.9	74.2	
18	2.4	339.5	46.5	2.5	348.1	52.3	
19	1459.4	357.7	59.4	2.5	359.6	58.9	
MEAN K = 70.1; alpha95 = 9.2; c.s.e. = 4.3		1.1	63.3				
MERIDEN		0.8	64.4				

Key: J = intensity ($mAm^{-1}x10^{-2}$); D = declination; I = inclination; AF = peak alternating demagnetising field (milliTesla); K = precision parameter; c.s.e. = circular standard error; alpha95 = semi-angle of the 95% cone of confidence. Samples 14 and 15 were lost during fieldwork. Samples 1–6, 8–10, 13, 17, and 20 disintegrated during cutting and have not been measured.

Table 3: results of archaeomagnetic analyses, Context [98]

SAMPLE	J	D	I	AF	D	I
3	2471.3	263.4	85.5	2.5	277.5	86.2
5	33015.7	328.7	34.7	2.5	328.8	34.7
8	4132.7	341.1	51.0	2.5	339.8	51.1
12	357.8	357.0	55.8	2.5	353.4	56.0
13	317.7	345.2	58.4	2.5	345.1	58.4
14	1679.9	327.4	22.7	2.5	328.4	23.0
MEAN K=12.5 Alpha95=19.8 c.s.e.=9.4		336.2	52.1			

Key: J = intensity ($mAm^{-1}x10^{-2}$); D = declination; I = inclination; AF = peak alternating demagnetising field (milliTesla); K = precision parameter; c.s.e. = circular standard error; alpha95 = semi-angle of the 95% cone of confidence. Samples 1, 2, 4, 6, 7, and 9–11disintegrated during cutting and have not been measured.

RADIOCARBON SAMPLING AND ANALYSIS

In 2008, following the excavation of furnace [135], a fragment of hazel charcoal was split radially and subsamples were dated by Accelerator Mass Spectrometry (AMS) at the Scottish Universities Environmental Research Centre (SUERC) and the Oxford Radiocabon Accelerator Unit (ORAU). The subsample dated at SUERC was pretreated by the acid-base-acid protocol (Stenhouse and Baxter 1983) and combusted to CO_2 in pre-cleaned sealed quartz tubes (Vandeputte *et al* 1996). The CO_2 was converted to graphite (Slota *et al* 1987) and measured as described by Xu *et al* (2004). The subsample measured at ORAU was prepared using methods outlined in Hedges *et al* (1989), converted to graphite and dated by AMS as described in Bronk Ramsey *et al* (2004).

Previously, two radiocarbon measurements had been obtained from the Centre for Isotope Research, Rijksuniversiteit Groningen, on bulk samples of short-lived charcoal from contexts in the fills of furnace [3] (oak sapwood) and the ore-roasting hearth [98] (birch). These samples were dated using Gas Proportional Counting of carbon dioxide. The samples were prepared using the acid/alkali/acid method (Mook and Waterbolk 1985) and dated as described by Mook and Stuerman (1983).

All three laboratories maintain continual programmes of quality assurance procedures, in addition to participation in international inter-comparisons (Scott 2003). These tests indicate no laboratory offsets and demonstrate the validity of the precision quoted.

The results (Table 4) are conventional radiocarbon ages (Stuiver and Polach 1977) and are quoted in accordance with the international standard known as the Trondheim convention (Stuiver and Kra 1986).

The calibrations of the results, relating the radiocarbon measurements directly to calendar dates have been calculated using the calibration curve of Reimer *et al* (2009) and the computer program OxCal v4.1 (Bronk Ramsey 1995; 1998, 2001, 2009). The calibrated date ranges cited in Table 4 have been calculated according to the maximum intercept method (Stuiver and Reimer 1986). They are quoted in the form recommended by Mook (1986), with the end points rounded outwards to decadal endpoints, or to 5 years if the radiocarbon error term is less that ±25. The graphical distributions of the calibrated dates (Fig 8) are derived from the probability method (Stuiver and Reimer 1993).

Table 4: Radiocarbon results

Lab No	Sample ID	Material and context	$\delta^{13}C$ (‰)	Radiocarbon Age (BP)	Calibrated date (95% confidence)
OxA-18598	LFW07 137A	Charcoal, single fragment, hazel (*Corylus avellana*) from immediately above baked sandstone floor of bloomery furnace [135]	-26.1	1883 ±24	cal AD 70–215
SUERC-17259	LFW07 137B		-25.8	1880 ±35	
weighted mean	T'=0.0; ν=1; T'(5%)=3.8; Ward and Wilson 1978)			1882 ±20	
GrN-28444	LFW03 [12]	Charcoal, bulk oak (*Quercus* sp.) sapwood (14g) from immediately above baked sandy floor of smelting furnace [3]	-	1850 ±30	cal AD 70–250
GrN-29609	LFW05 [59]	Charcoal, bulk birch (*Betula* sp.) (83g) from charred logs at base of roasting pit [98]	-	1800 ±20	cal AD 130–320

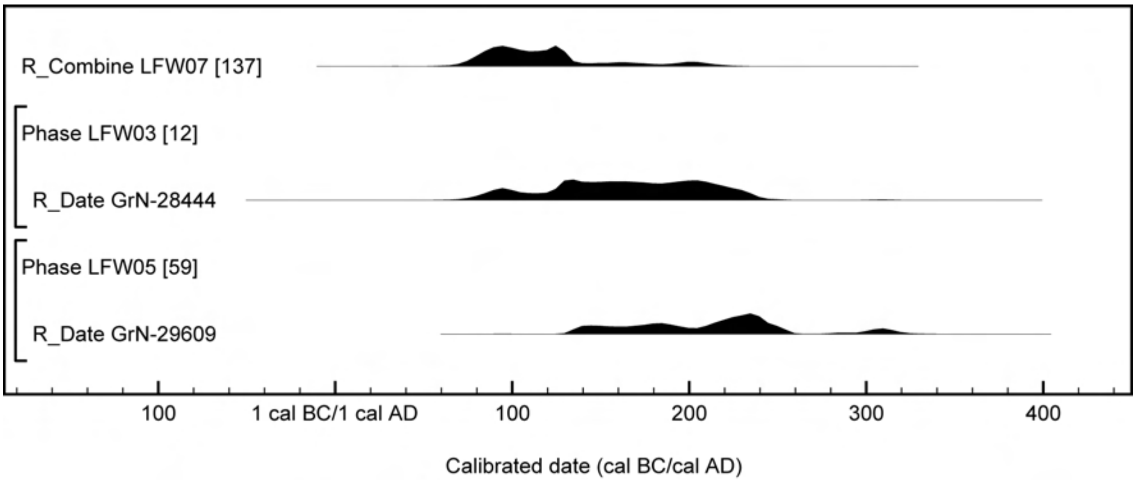

Figure 8: Probability distribution of radiocarbon dates from Little Furnace Wood. These distributions are the result of simple radiocarbon calibration (Stuiver and Reimer 1993). The height of each distribution at any point on the calendrical time-scale is proportional to the probability that the sample is of that calendar date

CONCLUSION

Charcoal from within furnace [135] has yielded a radiocarbon date of cal AD 70–215 (95% confidence; OxA-18598, 1883 ±24BP, and SUERC-17259, 1880 ±35BP), consistent with the earlier of the two date ranges obtained by archaeomagnetic dating (AD 60–220).

Charcoal from within furnace [3] yielded a radiocarbon date of cal AD 70–250 (95% confidence; GrN-28444; 1850 ±30 BP), apparently later than the archaeomagnetic date range of AD 40–60 (68% confidence). The charcoal from within the furnace (3), however, was part of the fill of the furnace, but was not associated with the final firing (the remains of which had been removed in antiquity), suggesting it had, perhaps, been derived from a hearth nearby and was used to backfill what was probably, by then, an old furnace. In this case, the calibrated radiocarbon result provides only a *terminus ante quem* for the archaeomagnetic date.

Radiocarbon analysis of charcoal from the ore-roasting hearth [98] yielded a date of cal AD 130–320 (95% confidence; GrN-29609; 1800 ±20 BP). The broad date range is consistent with finds of East Sussex ware, a native pottery type associated with the first to third centuries AD, but archaeomagnetic sampling was unable to confirm this date range, as the archaeomagnetic vectors are very poorly grouped.

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