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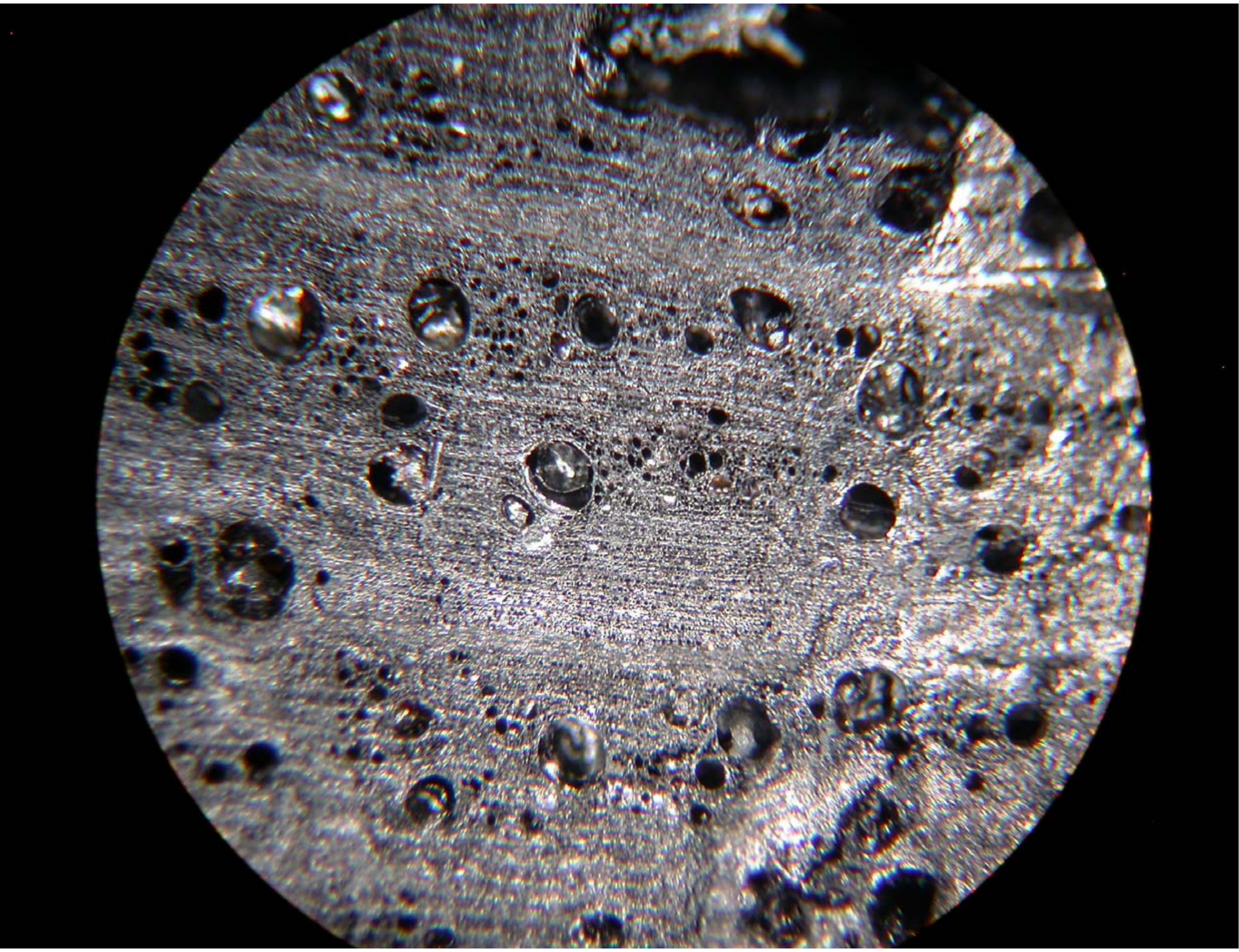
LEGGE'S MOUNT
THE TOWER OF LONDON, LONDON
ANALYSIS OF WOOD CHARCOAL FROM DEPOSITS ASSOCIATED WITH THE TUDOR ROYAL MINT

ENVIRONMENTAL STUDIES REPORT

Zoë Hazell



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London

Analysis of wood charcoal from deposits associated with the Tudor Royal Mint

Zoë Hazell

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SUMMARY
In the 1976 excavations of Legge's Mount (Tower of London), wood charcoal remains were recovered from deposits associated with the Tudor Royal Mint. Results of detailed analysis of the charcoal remains are presented here; the dominance of *Quercus* sp (oak) and *Fraxinus* sp (ash) indicates that these were the preferred wood types for fuelling the mint's furnace. *Betula* sp (birch) and *Corylus* sp (hazel) remains were also identified. As well as providing information on the selection for fuels, the presence of these taxa suggests their availability in the locality.

Key words: Charcoal, Post-Medieval, Wood

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ARCHIVE LOCATION
The archive will be deposited with the Historic Royal Palaces, Tower of London.

DATE OF RESEARCH
2010 to 2011

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INTRODUCTION

Excavations in 1976 of Legge's Mount (the northwest bastion of the Tower of London) encountered brick remains, that included the furnace – comprising two key-shaped hearths and an adjoining ash pit (see Parnell 1993: 59-60) – of the 16th century Tudor Royal Mint. From there, wood charcoal – presumed to represent fuel from the furnace – was recovered and sampled. Preliminary assessment work was carried out at the time (Keepax 1978), but this report presents the full analysis of the material.

Contextual information

The charcoal remains were found together with the metalworking crucibles (J Bayley, pers. comm.) that were reported to derive mainly from the ash pit (Parnell 1993: 59). Analysis of the crucibles showed them to contain both base and precious metals, as well as metal alloys (White and Kearns 2010); bone ash cupels, recovered from the furnace surrounds, had been used to refine silver (White 2010). Archaeomagnetic dating carried out on the furnace deposits indicated that the last use of the furnace was between AD1530 and 1560 (reported in Parnell 1993: 60).

WOOD CHARCOAL ANALYSIS

Methodologies

Sample description and processing

Two boxes of charcoal fragments were analysed; both labelled '375 LM76 (4)'. Both were from Layer 4, purported to have been hand-picked during the 1976 excavations.

Box 1 consisted of 10 fragments of wood charcoal and 1 unattached bark fragment, with minimal small debris and dust. This box required no processing before the fragments were examined.

Box 2 contained a greater number of charcoal fragments, and with noticeably more charcoal dust and smaller charcoal debris fragments. It also contained two original labels with 'No.6 LMT 76 (4)' hand-written and with the crown emblem and ER monogram printed. As the sample is thought to have been hand sampled, and as the very small fragments looked as if they were derived from post-sampling fragmentation, the remains from this box were gently sieved through 2mm and 4mm meshes, and analysed as follows:

- All the charcoal fragments with all three planes >4mm (136 in total) were examined, analysed and recorded individually. During sieving it also became evident that the multiple broken fragments that would have been produced during Keepax's (1978) analysis, had all been replaced into this same bag. Where readily achievable, fragments that were clearly derived from the same initial piece were re-grouped; this was only practicable on complete roundwood twigs with distinctive cross-sections and fractures. Although fragment counts and weights are usually considered when interpreting charcoal taxa assemblages, in this study only weights are used, because the charcoal remains had already been broken.
- For the fragments between 2mm and 4mm, only the charcoal fragments with all three planes >2mm were examined. These were initially grouped into taxa groups based on visual inspection with a hand lens, and subsequently confirmed using a low power light microscope (Leica MZ95). The identity of each group was then determined using a high power light reflective microscope.
- No fragments with any plane <2mm were examined.

Identifications

Charcoal fragments were broken to reveal clean, fresh surfaces of the three main planes of identification (transverse (TS), tangential longitudinal (TLS) and radial (RS) sections), and examined at high power magnification (x50 to x500) on an Olympus BH light reflective microscope.

Identifications were carried out using a combination of the guides by Schweingruber (1982), Hather (2000) and Gale and Cutler (2000). Identifications were only possible to genus level. Oak fragments could only be identified securely as such if multiseriate ray/s were seen; if none were present, then it was recorded as cf *Quercus* sp (oak) (because strictly speaking in the absence of multiseriate rays oak cannot be distinguished anatomically from *Castanea* sp (sweet chestnut)).

Other characteristics

In conjunction with the wood identifications, other features and measurements were recorded. Before any samples were broken, each fragment was weighed on an Oertling NB33 balance (grams; 3dps). Where the pith and (inner) bark were both present, the full radius of the fragment on the radial section was measured with Mitutoyo CD-8"CW digital callipers (mm; 2dps).

A checklist of other characteristics (see Marguerie and Hunot 2007) was devised to record:

- information on the growth rings; number (count), curvature (none, weak, moderate, strong, indeterminate)

- presence/absence of: pith, bark, reaction wood, tyloses, fungal hyphae/mycelium, degradation (insect/rootlet holes), radial fracture and vitrification (I (low), II (strong) and III (total fusion))

No comments on the presence/absence of working marks were made, because the fragments had already been broken (and thereby altered) for the previous assessment by Keepax (1978).

Given that the small fragment sizes of the 2-4mm fraction precluded estimation of ring curvature, wood maturity was assessed broadly, by examining the relevant taxa for tyloses (ie *Quercus* sp and *Fraxinus* sp) and separating fragments (by taxa) into presence and absence groups. These were then weighed separately.

RESULTS

Box 1

This box contained charcoal Fragments 1 to 11. The charcoal samples were dominated by *Quercus* sp (oak) (six fragments) and *Fraxinus* sp (ash) (three fragments), with one fragment of *Betula* sp (birch).

Box 2

This box contained Fragments 12 to 136, plus the remaining, un-numbered smaller fragments:

- numbered fragments (>4mm) (125 in total)
- un-numbered fragments (2-4mm) (190 in total)

Identifications

In total, four taxa were identified within this single sample; all were hardwoods (angiosperms): *Quercus* sp (oak), *Fraxinus* sp (ash), *Betula* sp (birch) and *Corylus* sp (hazel). As well as wood remains (wood and bark), fragments of a coal-like deposit were also recovered.

Quercus sp was identified from the combination of: a) ring porous vessel patterning, b) distinctive flame-like patterning of vessels in the latewood, c) both uniseriate and multiseriate rays and d) the presence of tyloses (indicating heartwood). *Fraxinus* sp was characterised by: a) ring porous vessel arrangement, b) the presence of solitary and radially-paired small vessels in the latewood, c) simple perforation plates and d) predominantly bi- and tri-seriate cell ray widths. *Betula* sp was characterised by: a) diffuse porous vessel pattern, with vessels in radial chains, b) scalariform perforation plates, c) very small vessel wall pits, d) rays mostly 1-3(4) cells wide and e) an absence of aggregate rays. *Corylus* sp was identifiable on the basis of: a) aggregate rays, b) scalariform perforation plates with widely-spaced bars (5-10), c) rays 1 cell wide (2-3 near aggregate rays) and d) large vessel wall pits.

Due to the presence of the flame-like latewood vessel patterning, it was possible to say that the *Quercus* sp (Fagaceae family) was a deciduous taxon, and within the British Isles, this includes only *Q. robur* (pedunculate oak) and *Q. petraea* (sessile oak) (Gale and Cutler 2000: 204). In terms of the *Fraxinus* sp (Oleaceae family), *F. excelsior* (ash) is the only native species from the British Isles. The native types of *Betula* sp (Betulaceae family) are *B. nana* (dwarf birch), *B. pendula* (silver birch) and *B. pubescens* (downy birch) (although hybrids also occur). *C. avellana* (hazel) is the only native *Corylus* sp (Betulaceae family) in the British Isles.

Abundances

The charcoal count results are presented in Table 1. All the same taxa were found in the >4mm fraction as in the 2-4mm fraction, and for each taxon, the weight of the 2-4mm fraction was less than c 2g; as these were so small, combining them with the >4mm fraction did not significantly change the total abundance results.

Table 1. Raw data (fragment count and weights) by taxa; shown separately per fraction (>4mm and 2-4mm) and as a combined total.

Taxa	>4mm fraction		2-4mm fraction		Totals	
	Fragment count	Weight (g)	Fragment count	Weight (g)	Fragment count	Weight (g)
Betula sp	30	25.3	31	0.431	61	25.731
cf *Betula* sp	2	2.976	-	-	2	2.976
Corylus sp	3	27.243	7	0.135	10	27.378
Fraxinus sp	23	63.925	34	0.978	57	64.903
Quercus sp	82	185.349	86	2.054	168	187.403
cf *Quercus* sp	9	0.811	-	-	9	0.811
Bark	10	7.266	32	1.174	42	8.440
Indeterminate	1	0.015	-	-	1	0.015
Coal	4	4.084	-	-	4	4.084
Totals	164	316.969	190	4.772	354	321.741

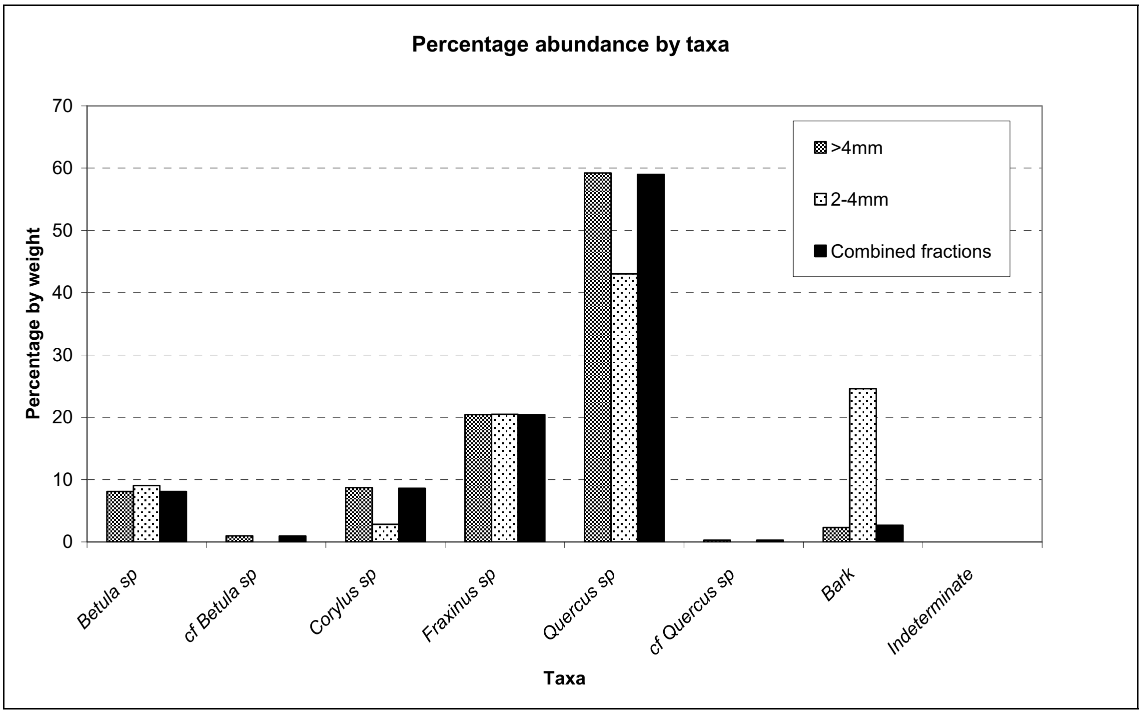
Table 2 and Figure 1 show the abundance of each taxon as percentages of each fraction and of the total. Weight is used here because it is not known to what degree the fragments were broken in previous studies, either purposely for identification or accidentally by general handling. The result of the combined two fractions is, again, not very different from the >4mm fraction on its own. The largest differences between fractions is for a) bark which is more abundant in the 2-4mm fraction (by c 22 per cent) and b) *Quercus* sp with more in the >4mm fraction (c 16 per cent).

The complete sample (ie all fragments >2mm) is dominated by (cf) *Quercus* sp (59.26 per cent by weight) and *Fraxinus* sp (20.43 per cent by weight), indicating that long-lived taxa dominate (totals c 80 per cent). Together, the short-lived taxa present in the sample ((cf) *Betula* sp and *Corylus* sp) comprise only c 18 per cent. Indeterminate fragments comprised only a very small amount of the total.

Table 2. Proportional abundances of total wood charcoal (ie not including the coal-like deposit) by weight (2dps)

	Percentage by weight (>4mm)	Percentage by weight (2-4mm)	Percentage by weight (total combined fractions)
Betula sp	8.09	9.03	8.10
cf *Betula* sp	0.95	0.00	0.94
Corylus sp	8.71	2.83	8.62
Fraxinus sp	20.43	20.49	20.43
Quercus sp	59.24	43.04	59.00
cf *Quercus* sp	0.26	0.00	0.26
Bark	2.32	24.60	2.66
Indeterminate	0.00	0.00	0.00

Figure 1. Diagram showing the proportional abundances of total wood charcoal (ie not including the coal-like deposit) by weight.



Other characteristics

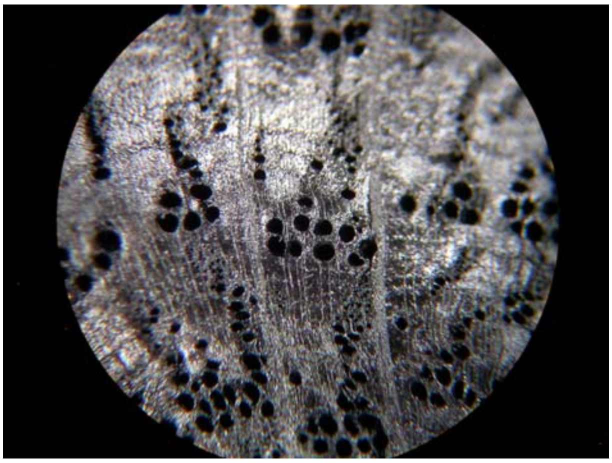
Other characteristics that were regularly recorded on the fragments from the >4mm fraction are summarised in Table 3 and detailed results are presented in Appendix 1.

Of all the fragments, complete, full cross-sections of small roundwoods were identified from only *Corylus* sp (n = 2; fragments 14 and 33) and *Quercus* sp (n = 5; fragments 32, 35, 59, 71, 72).

In the >4mm fraction, the complete radius was measured on fragments where both the pith and (inner) bark were present ie on roundwood branches, but not necessarily on complete circular cross-sections. Where this was possible, the largest measured radius for each taxon was: *Betula* sp 31.1mm, *Corylus* sp 14.8mm, *Fraxinus* sp 33.5mm and *Quercus* sp 33.8mm, giving branch diameters of c 62.2, 29.6, 67.0 and 67.6mm respectively (although dimensions will have shrunk in the carbonisation process). Of note, both small and large diameter branch sizes of *Quercus* sp were burnt; ranging from 11.4 to 67.6mm.

Also of interest was that on the small diameter twigs of oak, there was a clear offset within the annual rings, occurring at the multiseriate rays (Figure 2).

Figure 2. Photograph of Fragment 32 showing offset alignment of tree rings at the multiseriate rays (oak). The diameter of the field-of-view is c 4mm.



Assuming that each tree ring represented an annual growth ring, the oldest remains being burnt were of *Quercus* sp (79 years). Unsurprisingly, the remains with the most rings belonged to this longer-living taxon; where the complete radius (from pith to (inner) bark) was measurable, *Quercus* sp had a maximum of 79 rings and *Fraxinus* sp had a maximum of 43 rings. These two taxa also had tyloses; features associated with older/mature wood. Fungal hyphae were present only in *Quercus* sp remains (but not all the fragments) in the >4mm fraction, except for an occurrence in one fragment of *Fraxinus* sp.

The number of tree rings did not always positively correlate with the size (radius) of the wood; for example, in the case of *Fraxinus* sp, when comparing the minimum and maximum radial measurements (when pith and (inner) bark were both present) the smallest diameter fragment (45.2mm) actually had more growth rings (43) than the largest diameter fragment (67.0mm) which had 20 growth rings, giving average ring widths of 0.5mm and 1.7mm respectively. Given that ring widths can indicate wood growth speeds, this implies that larger sized wood might not necessarily represent older wood (ie more rings) but could result from faster wood growth (ie with fewer, but more-widely spaced, rings). In this case, the smaller of the *Fraxinus* sp fragments was actually older; assuming that each ring represented an annual growth ring, rather resulting from other factors (such as climate or pollarding) causing 'ghost' rings.

Table 3. Summary table showing the main characteristics, by taxa, of charcoal fragments from the >4mm fraction. Bold indicates the most frequently-occurring categories. For ring curvature: I = indeterminate, N = none, W = weak, M = moderate and S = strong. For tyloses and fungal hyphae, presence or absence is indicated by: Y = yes and N = no. For vitrification: I = low, II = strong and III = total fusion.

Taxa (>4mm)	Radial measurements of fragment (mm) (2dp)		Complete, measured radius (mm) (2dp) where pith and (inner) bark present		Ring curvature	Number of rings counted		Tyloses	Fungal hyphae	Vitrification
	Minimum	Maximum	Minimum	Maximum		Minimum	Maximum			
Betula sp	4.69	39.79	30.1	31.1	I, N, W, **M**, S	2	16	N	N	**II**, III
cf *Betula* sp	1.03	2.72	--	27.3	**M**, S	3	11	N	N	**II**, III
Corylus sp	5.51	14.8	11.1	14.8	M, **S**	6	10	N	N	**II**, III
Fraxinus sp	3.03	42.6	22.6	33.5	I, N, **W**, **M**, S	2	43	**Y**	Y, **N**	I, **II**, III
Quercus sp	3.26	44.7	5.72	33.84	I, N, **W**, M, **S**	2	70	**Y**, N	Y, **N**	I, **II**, III
cf *Quercus* sp	3.17	8.91	--	--	N, M, **S**	3	20	Y, **N**	**Y**, N	I, **II**, III

Table 3 shows that tyloses were present in fragments of both *Quercus* sp and *Fraxinus* sp; more detailed results distinguishing the presence and absence of tyloses in these two taxa, are shown in Table 4. Where the results indicate that fragments had tyloses present, this includes fragments that had both heart- (mature) and sap-wood (young). Due to this possible simultaneous presence and absence of tyloses on a single fragment, it was more appropriate for the results to be expressed as a proportion by fragments rather than by weight.

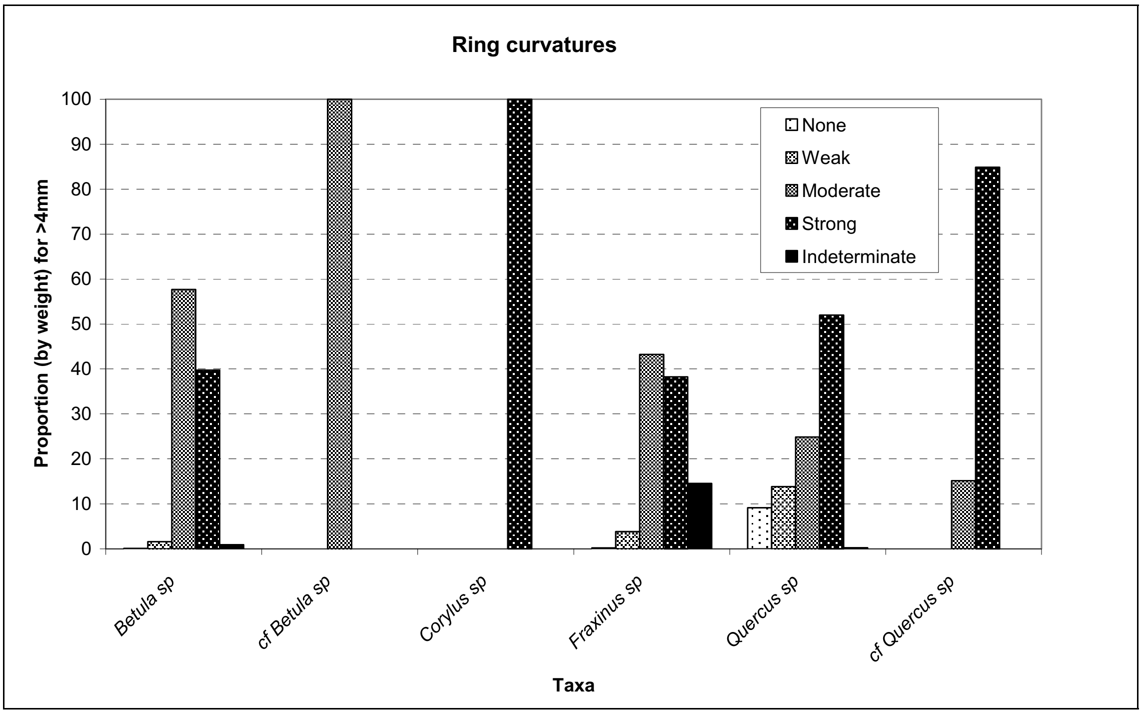
Table 4. Proportions of fragments with tyloses

	Proportion with tyloses by fragment count (percentage)		Proportion with tyloses by weight (percentage)	
Taxa	>4mm	2-4mm	>4mm	2-4mm
Fraxinus sp	100	85	100	89
Quercus sp	57	38	75	48
cf *Quercus* sp	22	n/r	27	n/r

In the >4mm fraction, calculated by weight, tyloses were present in all the *Fraxinus* sp fragments (100%), just over half the *Quercus* sp fragments (57%) and a fifth of the cf *Quercus* sp fragments (22%). Presence of tyloses suggests the fragment comes from heartwood (mature), and their absence suggests sapwood (young). In the 2-4mm fraction, the *Quercus* sp fragments were comprised of almost half heartwood (48%) and half sapwood (52%) and the *Fraxinus* sp fragments were dominated by heartwood (89%) compared to sapwood (11%).

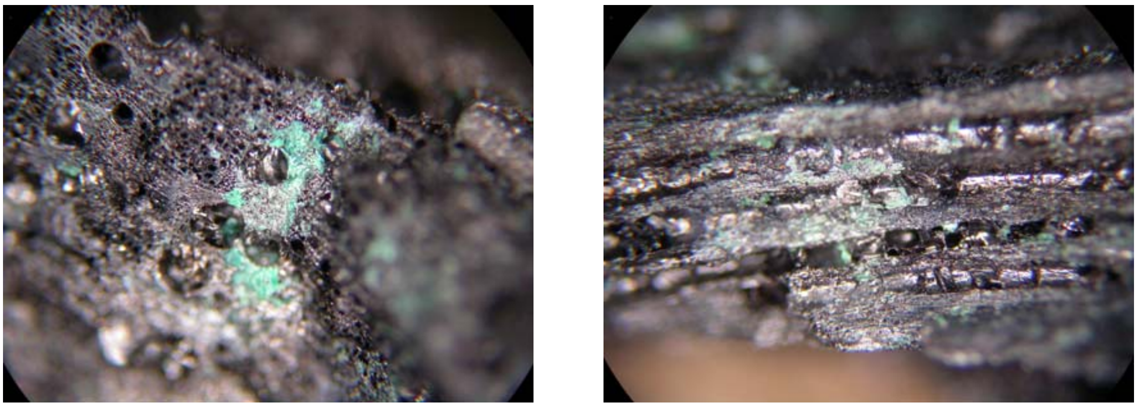
Ring curvatures were also recorded in the >4mm size fraction in order to facilitate the identification of particular wood sizes; see Table 3 for a summary and Figure 3 for detailed results. The most material of none/weak curvature was of *Quercus* sp, indicating that this was the oldest/largest material (such as trunk wood) used. However, both large and small components of *Quercus* sp were used, indicated by nearly half of the remains having strong curvature wood also present; indeed out of the seven complete small roundwood cross-sections recovered, five were from *Quercus* sp, one of which was possibly root. The largest amount of indeterminate material was from *Fraxinus* sp and this was because there were many fragments too small to determine curvature. As well as the complete small roundwood cross-sections recovered of *Quercus* sp, two *Corylus* sp twigs were identified.

Figure 3. Ring curvature results in the >4mm fraction, with curvature categories calculated as a percentage by weight, per taxon.



Occasional charcoal fragments (all of which were oak) had green-coloured (copper?) deposits on the outside and within the vessels (see Figure 4), reinforcing the association of the charcoal remains with the metalworking activities.

Figure 4. (a) and (b) Photographs of Fragment 127 (oak) showing green copper-coloured deposits on the charcoal. The diameter of the field-of-view is c 4mm.



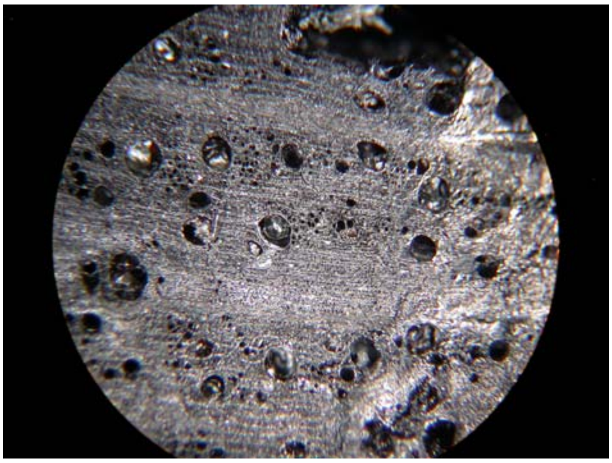
Charcoal vitrification

Many fragment/s of charcoal were vitrified, occurring to some degree in all the taxa.

Although the mechanisms resulting in vitrification of charcoal are not fully understood, it is no longer thought to result from reburning wood (ie using charcoal as fuel) or to be associated with high temperature burning (McParland *et al* 2010).

Within this sample, of particular interest was the presence of differential degrees of vitrification, particularly between heartwood and sapwood on the same fragments. Often, the heartwood (identified from the abundance of tyloses within the earlywood vessels) seemed to be extremely highly vitrified (see Figure 5); the sapwood appeared either not to be vitrified (individual ray cells were still clearly visible in its multiseriate rays), or very minimally.

Figure 5. Photograph of Fragment 4 (oak) illustrating the difference in vitrification between heartwood (on the right of the image) and sapwood (on the left of the image), with an intermediate 'transition zone'. The diameter of the field-of-view is c 4mm.



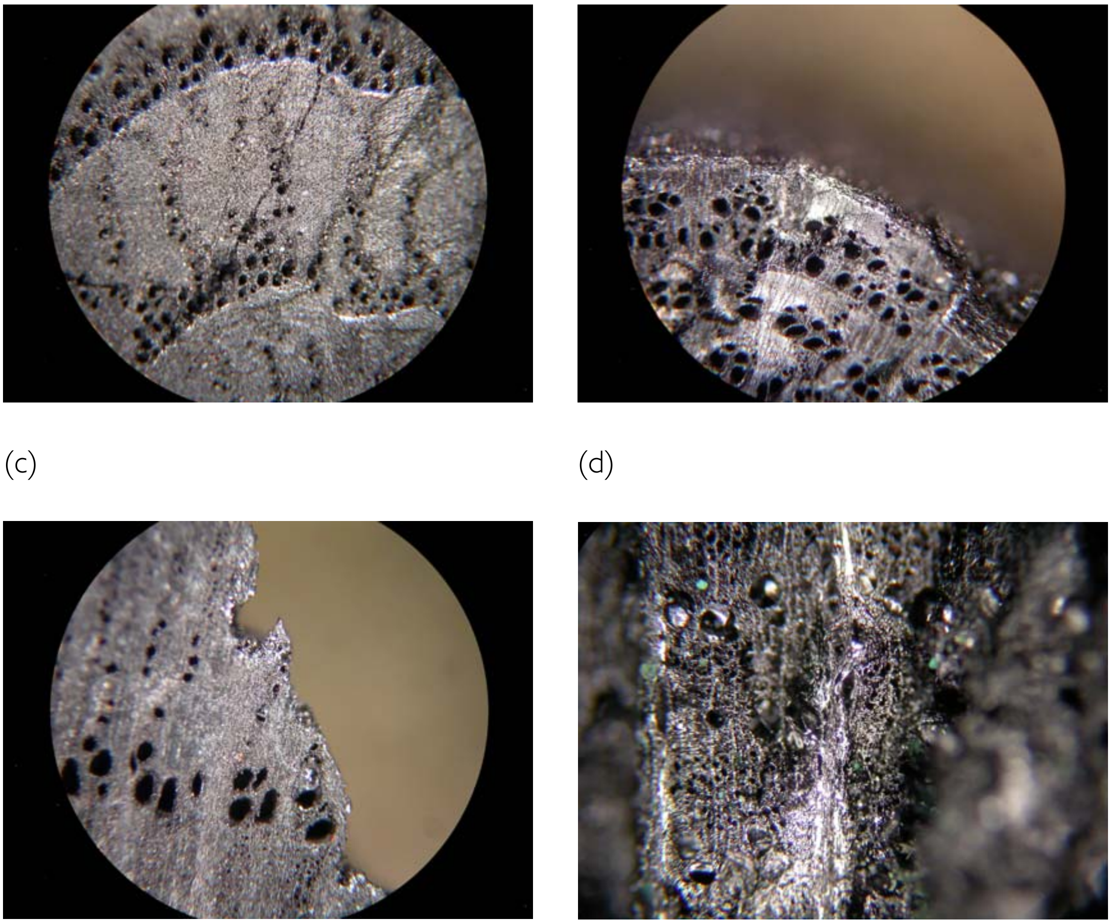
Vitrification also occurred preferentially:

- in heartwood over sapwood, resulting in clear differentiations between the two (Figure 5)
- as a narrow band that followed the growth ring boundary (Figure 6a)
- of the (inner) bark (Figure 6b)
- along the edges of broken (prior to burning?) fragments (Figure 6c)
- along the multiseriate rays of oak (Figure 6d)

Figure 6. Photographs showing examples of enhanced charcoal vitrification. (a) Fragment 53 (oak) shows vitrification along a growth ring boundary, (b) Fragment 72 (oak) of bark, (c) Fragment 56 (oak) along broken wood face, and (d) Fragment 46 along multiseriate rays (oak). The diameter of the field-of-view is c 4mm.

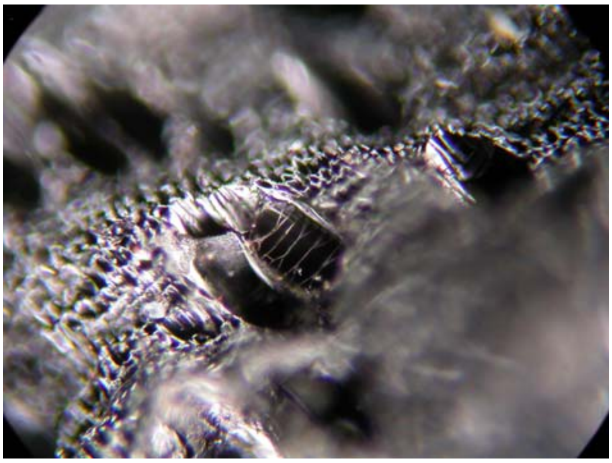
(a) (b)

(c) (d)



Sometimes, where vitrification was more pronounced, the bars of the scalariform perforation plates on Betulaceae were broken and fused to adjacent ones (Figure 7).

Figure 7. Photograph of Fragment 30 (cf birch) showing fused scalariform perforation plates. The diameter of the field-of-view is c 0.4mm.



DISCUSSION

Taxa present

In total, four taxa were recorded; oak, ash, birch, hazel.

By weight, the remains were dominated by (cf) oak, then, in descending order, ash, (cf) birch and hazel (although the last two were very similar in abundance). Some unidentifiable bark and indeterminate fragments were also present, as were a few fragments of coal-like material. It is likely that the bark became separated from the wood after burning, possibly during any historical raking or clearing of the remains, or more-recently during excavation, sampling or processing of the remains.

It is unsurprising that oak was the most common wood charcoal remain; it is commonly used and recovered from British archaeological sites as it is favoured for its good burning characteristics.

Size, age and condition of the wood

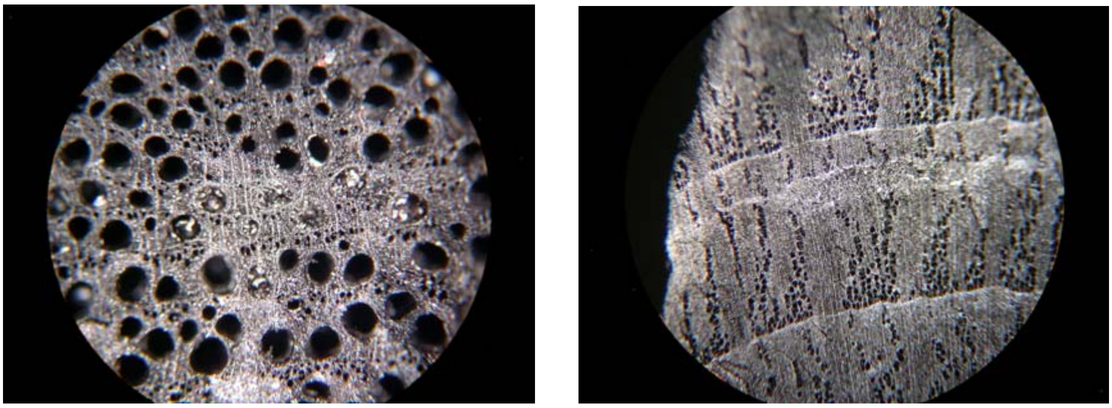
Inferred diameters, ring curvatures, the number of growth rings, and the presence of tyloses (where appropriate) all give indications as to the age and size of the wood being used for fuel.

Generally, the presence and absence of tyloses in the *Fraxinus* sp and (cf) *Quercus* sp remains indicate that both heart- and sap-wood, respectively, of both genera were being used as fuel. For British oaks (there are regional variations) sapwood represents the youngest, c 10-46 years (see English_Heritage 2004) of the outer growth of a tree, indicating that trees older than this were being burnt.

However, in some of the samples, there was inferred evidence of damage to the wood. For example, tyloses were present in discrete patches, and separate from any clear heartwood-sapwood boundary (see Figure 8a). Other evidence of possible damage came from the presence of scarred wood growth (see Figure 8b).

Figure 8. Photographs showing possible damage to the wood; (a) Fragment 2 showing a discrete patch of tyloses within an area of sapwood, (oak), and (b) Fragment 14 showing scar tissue within a growth ring (hazel). The diameter of the field-of-view is c 4mm.

(a) (b)



Inferences on wood types for kindling can be made based on the size and age of the wood. At this site, where complete radial measurements were possible (from pith to (inner) bark), the two smallest reconstructed diameters were of *Quercus* sp (11mm) and *Corylus* sp (22mm), suggesting that these twig-sized remains could have been used as kindling. The largest two reconstructed diameters belong to *Quercus* sp (68mm) and *Fraxinus* sp (67mm) suggesting that these could have been used as the main fuel types once temperatures were sufficient in the furnace; both taxa are relatively difficult to light, but once lit emit high levels of heat. Also of note is that large *Betula* sp remains were recovered (a maximum diameter of 62mm); this wood is easy to light and provides moderate-to-high heat when burning.

The curvature of the rings can also be used to infer the size of the wood being burnt; strong curves are indicative of small branches/twigs, moderate curves of medium branches and none/weak curvatures of trunk/large branch wood. The most prevalent curvatures of the *Quercus* sp wood were weak and strong (equally), suggesting that both large and smaller wood diameters were being used. This helps confirm the same inference based on the measured diameters of the *Quercus* sp remains (reported above). For *Corylus* sp, the dominance of strong ring curvatures also supports the same inference that was made for this taxon based on the measured diameters ie that small diameter wood (twigs) were being burnt.

The overall ratio of long- to short-lived taxa is c 4.4:1, suggesting that the preferred fuels were the longer-lived, longer-burning and generally higher heat-emitting types.

The presence of fungal hyphae suggests that wood was already dead when it was burnt. Within this sample, this feature was most commonly encountered in oak, and occasionally in ash. It is not possible to determine whether this wood was collected as dead wood, or felled and then stored – during which time decay could have occurred – prior to burning.

Charcoal vitrification

The results suggest that there *might* be a link between the degree of vitrification (and/or the ease with which vitrification can occur) and a) the presence of tyloses (usually manifest as the heartwood, but also in a damaged section of wood) or b) the bark. It could be related to the proximity/density of cells/wood tissue, for example in clustered ray cells, at the end of growth year, presence of tyloses.

CONCLUSIONS

Analysis of the wood charcoal remains recovered from the sample from Legge's Mount mint has provided an insight into the fuelwoods of choice for fuelling this industrial feature and has also indicated which trees were likely to have been present in the area during the Tudor period. The wood identification results have suggested that the main fuel type used was oak, and to a lesser extent ash. Lesser amounts of birch and hazel were also used.

It is inferred that charcoal (rather than wood) would have been used as the fuel at this site, given that its use associated with smelting and other metal-processing methods is stressed in '*The Pirotechnia of Vannoccio Biringuccio*' (edited and translated by Smith and Gnudi 1979) with the statements "*In all these* [processes] *quantities of charcoal and various kinds of it must be handled continually... it is the food that nourishes the fire both for smelting and for softening the metals, or for calcining or drying things out.*" (page 173) and "*Charcoal is among the most important materials for smelting...*" (page 174). The presence of a coal-like deposit suggests that coal may also have been burnt, although recovered remains were few.

From the measured diameter and ring curvature results, it is inferred that both small- (ie twig) and large- (ie trunk/large branch) sized sections of oak were being burnt. The smaller diameter oak and hazel twigs could have been used as kindling, together with the birch, that, similar to hazel, is relatively easy to light. The larger oak and ash sections could then have been used as the main fuel once the fire was well established.

Vitrification was a common feature on charcoal fragments within the sample, but present to different degrees both between and within fragments. Of particular note was the clear difference in the degree of vitrification between oak heart- and sap-wood.

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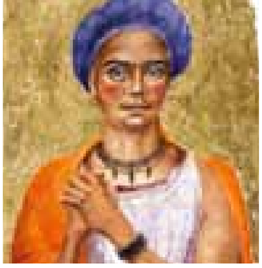
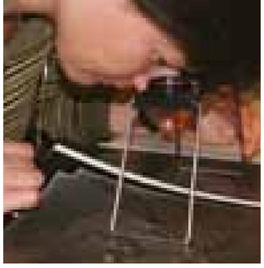
APPENDIX

Fragment number	ID	Weight (g)	Total no. rings	Maximum radial measurement (mm)	Ring curvature	Bark	Pith	Measured radius	Reaction wood	Tyloses	Fungal hyphae	Vitrification	Radial cracks	Corners	Notes
1	Fraxinus	16.623	43	22.57	Strong	Yes	Yes	22.57	No	Yes	No	II and III	Yes	Angular	
2	Quercus	5.92	38	20.76	None	No	No	-	Yes	Yes	No	II and III	No	Angular	
3	Betula	9.3	12	31.09	Strong	Yes	Yes	31.09	Yes	No	No	II and III	Yes	Subangular	Knotted
4	Quercus	17.783	40	44.68	Moderate	Yes	No	n/r	No	Yes	No	II and III+	Yes	Angular	
5	Quercus	11.587	25	23.83	Moderate	No*	No	n/r	No	Yes	No	II and III	Yes	Angular	
6	Fraxinus	14.59	15	17.97	Moderate	Yes	No	n/r	Yes	Yes	No	II and III	No	Angular	
7	Quercus	8.014	33	40.69	None	No	No	n/r	No	Yes	No	II and III+	Yes	Angular	
8	Fraxinus	9.283	12	13.97	Indet	Yes	No	n/r	Yes	Yes	No	II and III+	Yes	Angular	
9	Quercus	16.476	70	20.4	Strong	No*	Yes	20.44	No	Yes	No	II and III	Yes	Angular	?root
10	Quercus	1.769	22	30.05	Weak	No	No	n/r	No	Yes	No	II and III+	Yes	Angular	
11	Bark	0.621	-	-	-	Yes	-	1.77	-	-	-	II and III	-	Angular	
12	Betula	12.902	16	39.79	Moderate	Yes	No*	30.67	No	No	No	II and III	Yes	Subangular	
13	Quercus	51.723	79	33.84	Strong; moderate	Yes	No*	33.84	Yes	Yes	No	II	Yes	Subrounded	
14	Corylus	22.522	10	14.8	Moderate; strong	Yes	Yes	14.8	Yes	No	No	II	No	Subangular	
15	Quercus	2.124	25	23.13	Strong	No*	No*	24.3	No	Yes	No	II and III	Yes	Angular	
16	Quercus	3.974	31	19.31	Moderate; weak	No*	No	n/r	No	Yes	No	II	Yes	Subangular	
17	Quercus	2.241		23.86	None	No	No	n/r	No	Yes	No	II and III	Yes	Subangular	
18	Quercus	2.234	21	15.8	Weak; moderate	Yes	No	n/r	No	No	No	II and III	No	Subangular	
19	Quercus	8.944	12	23.59	Weak	Yes	No	n/r	No	No	No	II	No	Subangular	
20	Quercus	4.975	70	20.79	Weak	No	No	n/r	No	Yes	No	II and III	Yes	Subangular	
21	Fraxinus	8.972	29	42.62	Moderate	Yes	No	n/r	No	Yes	No	II	Yes	Angular	
22	Quercus	3.914	12	24.2	Moderate	Yes	No	n/r	No	No	No	II	No	Subangular	
23	Quercus	2.949	12	25.05	Weak	No	No	n/r	No	No	No	II	No	Angular	
24	cf Betula	1.394	11	27.24	Moderate	Yes	Yes	27.29	Yes	No	No	II and III	Yes	Subrounded	
25	Quercus	2.423	9	13.94	Strong	Yes	Yes	13.94	No	No	No	I	No	Subangular	
26	Fraxinus	3.236	20	33.31	Strong	No	No	33.51	No	Yes	No	II	Yes	Angular	
27	Quercus	1.587	29	8.77	Moderate; weak	No	No	n/r	Yes	No	No	I	No	Rounded	
28	Fraxinus	2.689	16	14.25	Weak; strong	Yes	No	n/r	No	Yes	No	II	No	Angular	
29	Quercus	1.231	11	18.75	Weak; none	No	No	n/r	No	No	No	II	No	Angular	
30	cf Betula	1.582	8	22.95	Moderate	No	No	n/r	Indet	No	No	II and III	Yes	Rounded	
31	Quercus	1.591	11	11.19	Strong	No*	Yes	11.19	No	No	No	II	No	Angular	
32	Quercus	8.237	12	8.56	Strong	No*	Yes	8.8	No	No	No	II	Yes	Angular	
33	Corylus	4.423	9	11.09	Strong	Yes	Yes	11.09	Yes	No	No	II	Yes	Subangular	
34	Fraxinus	1.535	12	16.24	Weak	No	No	n/r	No	Yes	No	I and II	Yes	Angular	
35	Quercus	0.747	45	10.29	Strong	No*	Yes	10.14	No	Yes	Yes	II	No	Subangular	
36	Quercus	1.208	13	21.54	Weak; none	Yes	No	n/r	No	No	No	I	Yes	Angular	
37	Quercus	1.64	19	14.32	Moderate; weak	Yes	No	n/r	Yes	Yes	No	II and III	No	Angular	
38	Quercus	1.117	20	17.74	Weak; none	No	No	n/r	No	Yes	No	II	No	Subangular	
39	Fraxinus	1.414	15	16.32	Strong; moderate; weak	Yes	No	n/r	Yes	Yes	Yes	II	Yes	Angular	
40	Quercus	1.339	10	11.81	Stong; moderate	No*	Yes	11.81	No	Yes	Yes	II	Yes	Angular	
41	Quercus	1.529	21	14.51	Moderate; weak	Yes	No	n/r	Yes	Yes	No	II and III	No	Angular	
42	Fraxinus	0.974	10	12.84	Moderate	No	No	n/r	No	Yes	No	II	Yes	Subangular	
43	Fraxinus	1.084	12	14.93	Moderate	No	No	n/r	No	Yes	No	II and III	Yes	Angular	
44	Quercus	0.816	8	9.87	Strong; moderate	Yes	No	n/r	No	Yes	Yes	I	No	Subangular	
45	Bark	0.843	-	-	-	Yes	-	-	-	-	-	II and III	No	Rounded	
46	Quercus	0.777	23	18	Weak; none	No	No	n/r	No	Yes	No	III	Yes	Angular	
47	Quercus	0.864	17	7.06	Moderate	Yes	No	n/r	No	No	No	I	No	Angular	
48	Quercus	0.725	11	13.29	Strong	No	Yes	n/r	Yes	Yes	Yes	II	No	Angular	
49	Fraxinus	1.347	16	13.67	Moderate; weak	No	No	n/r	Yes	Yes	No	II	No	Angular	
50	Bark	0.418	-	-	-	Yes	-	-	-	-	-	II and III	No	Angular	
51	Coal	1.287	-	-	-	-	-	-	-	-	-	-	-	Angular	
52	?Betula	0.51	7	15.03	Moderate	No*	No	n/r	Yes	No	No	II and III	No	Angular	
53	Quercus	0.719	7	8.2	Strong	No*	Yes	9.31	No	No	No	II and III	No	Subangular	
54	Bark	0.487	-	-	-	Yes	-	-	-	-	-	II and III	-	Subrounded	
55	Quercus	0.261	6	6.03	Strong	Yes	No	n/r	No	No	Yes	II	No	Angular	
56	Quercus	0.554	8	16.19	Moderate	No	No	n/r	No	No	No	II and III	No	Subangular	
57	Bark	0.436	-	-	-	Yes	-	-	-	-	-	II and III	-	Subrounded	
58	?Betula	0.455	7	14.69	Strong	No*	No	n/r	Yes	No	No	II and III	No	Rounded	
59	Quercus	1.424	12	5.35	Strong	Yes	Yes	5.91	No	No	Yes	II and III	No	Subangular	
60	Quercus	0.241	3	4.65	Weak	No	No	n/r	No	Yes	No	II and III	No	Angular	
61	?Betula	0.23	3	13.93	Moderate	No	No	n/r	Yes	No	No	II and III	No	Angular	
62	Coal	0.728	-	-	-	-	-	-	-	-	-	-	-	Angular	
63	Quercus	0.472	5	8.08	Weak	No	No	n/r	No	Yes	Yes	II	Yes	Angular	
64	Fraxinus	0.391	8	10.34	Strong	No	No	n/r	No	Yes	No	II and III	Yes	Angular	
65	Quercus	0.487	9	6.56	Strong	No*	Yes	7.97	No	No	No	II and III	No	Angular	
66	Coal	1.041	-	-	-	-	-	-	-	-	-	-	-	Angular	
67	cf Quercus	0.312	6	8.91	Strong	No	No	n/r	No	No	Yes	I	No	Angular	
68	?Betula	0.236	5	10.33	Moderate	No*	No	n/r	No	No	No	III	Yes	Rounded	
69	Fraxinus	0.58	11	13.83	Weak	No	No	n/r	No	Yes	No	II	No	Subangular	
70	Quercus	0.273	14	11.99	Weak	No	No	n/r	Yes	Yes	No	II	No	Angular	
71	Quercus	4.09	6	6.31	Strong	No*	Yes	7.72	No	No	No	II	No	Angular	
72	Quercus	2.278	8	5.72	Strong	No*	Yes	5.72	Yes	No	No	II and III	No	Subangular	
73	Bark	0.488	-	-	-	-	-	-	-	-	-	-	-	Subangular	
74	Bark	0.577	-	-	-	-	-	-	-	-	-	-	-	Subangular	
75	Fraxinus	0.459	5	10.03	Moderate	No	No	n/r	No	Yes	No	II	No	Angular	
76	Fraxinus	0.237	9	6.3	Weak	No	No	n/r	No	Yes	No	II	No	Angular	
77	Fraxinus	0.206	8	9.79	Moderate	No	No	n/r	No	Yes	No	II	Yes	Angular	
78	Fraxinus	0.081	4	7.59	Strong	No	No	n/r	No	Yes	No	II	No	Subrounded	
79	Fraxinus	0.052	2	3.7	None/indet	No	No	n/r	No	Yes	No	II	No	Subangular	
80	Fraxinus	0.02	3	3.03	None	No	No	n/r	No	Yes	No	II and III	No	Angular	
81	Fraxinus	0.051	2	3.99	None/indet	No	No	n/r	No	Yes	No	II	No	Angular	
82	Fraxinus	0.031	3	5.88	Weak	No	No	n/r	No	Yes	No	II	No	Subrounded	
83	Fraxinus	0.003	2	4.13	None/indet	No	No	n/r	No	Yes	No	II	No	Subrounded	
84	Quercus	0.288	8	10.03	Weak	No	No	n/r	No	Yes	No	III	Yes	Subangular	
85	Quercus	0.156	6	7.24	Weak	No	No	n/r	-	Yes	No	II	No	Angular	
86	Quercus	0.206	8	11.02	Moderate	No	No	n/r	-	Yes	No	III	Yes	Angular	
87	Quercus	0.109	5	6.39	Strong	No*	No	-	-	No	Yes	III	No	Subangular	
88	Quercus	0.093	6	5.75	Strong	No*	No	-		No	No	II and III	No	Angular	
89	Quercus	0.114	13	7.2	None	No	No	n/r	No	Yes	-	III	Yes	Subangular	
90	?Quercus	0.021	20	5.32	None	No	No	n/r	Yes	Yes	No	II	No	Rounded	
91	Quercus	0.188	8	9.59	Strong	No*	No	-	-	Yes	Yes	III	Yes	Angular	
92	Quercus	0.078	7	6.51	Strong	No	No	n/r	-	Yes	No	III	No	Angular	
93	cf Quercus	0.036	5	4.9	Moderate	No	No	n/r	-	No	Yes	II	No	Angular	
94	Quercus	0.141	8	7.69	Strong	Yes	Yes	7.69	-	No	No	II	No	Angular	
95	cf Quercus	0.05	6	6.5	Strong	No	No	n/r	-	No	Yes	II	No	Angular	
96	Quercus	0.123	7	7.91	None	No	No	n/r	-	Yes	No	III+	Yes	Angular	
97	cf Quercus	0.048	7	7.4	Moderate	No*	No	-	-	Yes	No	II	No	Angular	
98	Fraxinus	0.067	2	3.81	Weak	No	No	n/r	-	Yes	No	III	No	Angular	
99	Quercus	0.179	11	11.19	Moderate	No*	No	-	-	Yes	Yes	II	No	Subangular	

Fragment number	ID	Weight (g)	Total no. rings	Maximum radial measurement (mm)	Ring curvature	Bark	Pith	Measured radius	Reaction wood	Tyloses	Fungal hyphae	Vitrification	Radial cracks	Corners
100	cf Quercus	0.107	6	5.72	Strong	No*	No	-	-	No	Yes	II	No	Angular
101	Quercus	0.112	10	10.69	Weak	No	No	n/r	-	No	No	II	Yes	Subangular
102	cf Quercus	0.174	6	4.63	Strong	No	No	n/r	-	Yes	Yes	III	No	Angular
103	Quercus	0.085	4	4.42	Strong	No	No	n/r	-	No	Yes	II	No	Subangular
104	Quercus	0.064	11	4.96	Weak	No*	No	-	-	No	No	II	No	Subangular
105	Quercus	0.162	9	9.11	Indet	No	No	n/r	-	No	No	III	Yes	Angular
106	Quercus	0.234	9	11.25	Weak	No	No	n/r	-	Yes	No	III	Yes	Angular
107	Quercus	0.26	8	10.75	Weak	No	No	n/r	-	Yes	No	III+	Yes	Angular
108	Quercus	0.116	4	7.84	None	No	No	n/r	No	No	No	III	No	Subangular
109	Quercus	0.078	7	5.43	Strong	No	No	n/r	-	No	No	II and III	Yes	Subangular
110	Quercus	0.143	5	7.26	Weak	No	No	n/r	-	Yes	Yes	III+	No	Angular
111	Quercus	0.011	4	3.45	Strong	No	Yes	n/r	Yes	No	No	II	No	Angular
112	Quercus	0.162	13	7.07	Weak/indet	No	No	n/r	No	Yes	No	III	Yes	Angular
113	Quercus	0.202	7	8.76	Weak	No	No	n/r	No	Yes	No	III+	Yes	Angular
114	Quercus	0.12	8	8.75	Indet	No	No	n/r	No	Yes	Yes	III	Yes	Angular
115	Quercus	0.073	10	8.47	Indet	No	No	n/r	-	Yes	No	III+	Yes	Angular
116	cf Quercus	0.045	3	4.59	Strong	No	No	n/r	-	No	Yes	II	No	Angular
117	Quercus	0.036	8	6.54	None	No	No	n/r	-	No	No	III	No	Angular
118	cf Quercus	0.01	5	3.17	Moderate	No*	No	n/r	-	No	Yes	II	No	Angular
119	Quercus	0.036	4	3.61	Moderate	No	No	n/r	-	No	No	II	No	Subangular
120	Quercus	0.052	7	9.24	None	No	No	n/r	-	Yes	No	III	Yes	Subangular
121	Quercus	0.048	4	5.68	None	No	No	n/r	-	Yes	No	III	Yes	Angular
122	Quercus	0.099	6	6.33	None	No	No	n/r	-	Yes	No	III	Yes	Subangular
123	Quercus	0.044	3	4.47	Strong	No	No	n/r	-	No	No	II and III	Yes	Subrounded
124	Quercus	0.043	3	5.27	Indet	No	No	n/r	-	Yes	No	III	Yes	Angular
125	cf Quercus	0.029	4	5.21	Moderate	No	No	n/r	-	No	Yes	II	No	Angular
126	Quercus	0.027	5	10.72	None/indet	No	No	n/r	-	No	No	I	No	Subrounded
127	Quercus	0.053	8	9.33	None	No	No	n/r	-	Yes	No	III	Yes	Angular
128	Quercus	0.004	5	3.9	Strong	No	No	n/r	-	No	No	II	No	Angular
129	Quercus	0.001	15	3.26	None	No	No	n/r	-	No	No	II	No	Subangular
130	Quercus	0.017	2	5.46	Indet/none	No	No	n/r	-	Yes	No	III	Yes	Subangular
131	Quercus	0.011	16	4.45	None	No	No	n/r	-	No	No	I	No	Subrounded
132	Bark	0.155	-	-	Indet	Yes	-	-	-	-	-	II and III	-	Subrounded
133	Quercus	0.056	13	4.41	Weak	No	No	n/r	-	Yes	Yes	II	No	Subrounded
134	Bark	0.087	-	-	Indet	Yes	-	-	-	-	-	II and III	-	Angular
135	Quercus	0.009	10	4.99	Deformed	No	No	n/r	-	Yes	No	II and III	No	Subrounded
136	Quercus	0.038	-	-	-	No	No	n/r	Yes	Yes	No	II	No	Subrounded
137	Indet	0.015	-	-	-	-	-	-	Yes	-	-	-	-	Subrounded
138	Corylus	0.298	6	5.51	Strong	Yes	No	n/r	No	No	No	II and III	No	Angular
139	Betula	0.174	6	9.31	Moderate	No*	No	n/r	Yes	No	No	II and III	No	Angular
140	Betula	0.152	6	12.91	Moderate	No	No	n/r	No	No	No	II and III	No	Subrounded
141	Betula	0.124	3	6.07	Moderate	No*	No	n/r	No	No	No	II and III	No	Subangular
142	Betula	0.055	7	13.57	Weak	No	No	n/r	No	No	No	II and III	Yes	Subangular
143	Betula	0.071	7	11.67	Indet	No	No	n/r	No	No	No	II and III	Yes	Subangular
144	Betula	0.132	6	16.52	Strong	No	No	n/r	Yes	No	No	II and III	No	Subrounded
164	Betula	0.165	5	13.73	Weak	Yes	No	n/r	No	No	No	II	No	Subangular
165	Betula	0.033	4	7.74	Weak	No	No	n/r	No	No	No	II	No	Subangular
166	Betula	0.024	5	4.69	Moderate	No*	No	n/r	Yes	No	No	II and III	No	Subangular
167	Betula	0.049	4	9.25	Moderate	No	No	n/r	No	No	No	II	No	Angular
168	Betula	0.038	5	11.16	Weak	No	No	n/r	No	No	No	II	No	Angular
169	Betula	0.115	5	15.24	Strong	No	No*	n/r	No	No	No	II	No	Angular
170	Betula	0.043	6	5.39	Weak	No*	N	n/r	Yes	No	No	II and III	No	Subangular
171	Betula	0.027	8	9.8	Strong	No	No*	n/r	No	No	No	II	No	Subangular
172	Betula	0.013	2	5.08	Weak	No	No	n/r	No	No	No	II	No	Angular
173	Betula	0.125	12	18.92	Moderate	No*	No*	n/r	No	No	No	II and III	No	Subrounded
174	Betula	0.05	5	9.51	Moderate	No	No	n/r	No	No	No	II	No	Angular
175	Betula	0.023	3	8.18	Strong	No	No	n/r	No	No	No	II	No	Subangular
176	Betula	0.028	5	7.08	Weak	No	No	n/r	No	No	No	II and III	Yes	Angular
177	Betula	0.027	2	5.68	Weak	No	No	n/r	No	No	No	II	No	Angular
178	Betula	0.025	3	5.69	None	No	No	n/r	No	No	No	II	No	Subangular
179	Betula	0.014	3	6.88	Moderate	No	No	n/r	No	No	No	II	No	Subangular
180	Betula	0.044	2	5.27	Indet	No	No	n/r	No	No	No	II	Yes	Subangular
181	Betula	0.116	3	11.6	Indet	No	No	n/r	No	No	No	III	Yes	Subangular
145 to 146	Coal	1.028												Angular
147 to 163	Bark	3.154												Subangular


ENGLISH HERITAGE RESEARCH AND THE HISTORIC ENVIRONMENT

English Heritage undertakes and commissions research into the historic environment, and the issues that affect its condition and survival, in order to provide the understanding necessary for informed policy and decision making, for the protection and sustainable management of the resource, and to promote the widest access, appreciation and enjoyment of our heritage. Much of this work is conceived and implemented in the context of the National Heritage Protection Plan. For more information on the NHPP please go to http://www.english-heritage.org.uk/professional/protection/national-heritage-protection-plan/.

The Heritage Protection Department provides English Heritage with this capacity in the fields of building history, archaeology, archaeological science, imaging and visualisation, landscape history, and remote sensing. It brings together four teams with complementary investigative, analytical and technical skills to provide integrated applied research expertise across the range of the historic environment. These are:

* Intervention and Analysis (including Archaeology Projects, Archives, Environmental Studies, Archaeological Conservation and Technology, and Scientific Dating)
* Assessment (including Archaeological and Architectural Investigation, the Blue Plaques Team and the Survey of London)
* Imaging and Visualisation (including Technical Survey, Graphics and Photography)
* Remote Sensing (including Mapping, Photogrammetry and Geophysics)

The Heritage Protection Department undertakes a wide range of investigative and analytical projects, and provides quality assurance and management support for externally-commissioned research. We aim for innovative work of the highest quality which will set agendas and standards for the historic environment sector. In support of this, and to build capacity and promote best practice in the sector, we also publish guidance and provide advice and training. We support community engagement and build this in to our projects and programmes wherever possible.

We make the results of our work available through the Research Report Series, and through journal publications and monographs. Our newsletter *Research News*, which appears twice a year, aims to keep our partners within and outside English Heritage up-to-date with our projects and activities.

A full list of Research Reports, with abstracts and information on how to obtain copies, may be found on www.english-heritage.org.uk/researchreports

For further information visit www.english-heritage.org.uk

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