FLORE’S HOUSE, HIGH STREET, OAKHAM, RUTLAND
TREE-RING ANALYSIS OF TIMBERS
SCIENTIFIC DATING REPORT
Alison Arnold, Robert Howard, Matt Hurford and Cathy Tyers
FLORE’S HOUSE,
HIGH STREET,
OAKHAM, RUTLAND

TREE-RING ANALYSIS OF TIMBERS

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SUMMARY
Analysis by dendrochronology was undertaken on 48 out of 58 samples (ten having insufficient rings) from three ranges of Flore's House, Oakham: the hall range and the north and south cross-wings. This resulted in the production of four site chronologies, OKMASQ01–04. These comprise 18, 9, 10, and 2 samples, with overall lengths of 220, 184, 90, and 81 rings respectively. The rings of the first three site chronologies can be dated as spanning the years AD 1173–1392, AD 1408–1591, and AD 1570–1659, whilst the fourth site chronology is undated.

Interpretation of the sapwood and the heartwood/sapwood boundaries on the dated samples indicates the presence of four distinct phases of felling. The hall range roof and a single plate from the ground floor represent the earliest dated phase of construction, using timber all probably felled in AD 1378. The south cross-wing utilises timber with an estimated felling date in the range circa AD 1407–10. The inserted ceiling and a ground floor post in the hall range use timber felled in AD 1591. The roof of the north cross-wing uses timber felled in AD 1659, despite having a roof of similar design to that of the south cross-wing. Nine measured samples are ungrouped and undated.

CONTRIBUTORS
Matt Hurford, Alison Arnold, Robert Howard, and Cathy Tyers

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Flore’s House, a grade II* listed building located on the south side of the High Street, Oakham (SK8604108732, Figs 1–3), is one of the most important surviving medieval houses in Rutland (Hill 2007 unpubl). It has been associated with William Flore, who was controller of the works at Oakham Castle in AD 1373–80 (Barley 1975, 38), or with his son Roger, also a prominent man, who was Speaker of the Commons on four occasions in the early fifteenth century (Roskell 1957).

The following information is summarised from both Barley (1975) and Hill (2007 unpubl). The earliest part of the building is the hall range, oriented at right angles to the High Street (Fig 4). It is of three bays, incorporating two trusses of base cruck type and a truss at each end. The base cruck timbers are set within slots in the stone walls. The trusses have a cranked tiebeam and arch braces with spandrel struts. The upper roof is of crown post type, with bracing to the collar and crown plate (Fig 5). There are seven rafters in each bay, except the northernmost, which has three, due to it being truncated by the north cross-wing. The hall was originally a large, single-volume space, heated by a central hearth, with no chimney stack. The original timbers have heavy smoke-blackening. Over the centre of the hall, there is evidence for a former louvre to allow smoke to escape.

The hall, which is of unusually large size for a town house, had a cross passage at its south end (Fig 6). The timbers in the cross passage comprise a central north-south ceiling beam, from either side of which run five east-west joists. The ceiling of the corridor running north from the cross passage comprises four north-south joists. With the exception of timbers in the cross passage and corridor, only a small section of the inserted floor of the hall range is visible, due to the insertion of modern ceilings. The front doorway has jambs with attached shafts and a moulded pointed arch. Barley (1975) and Pevsner (1974) thought that the doorhead is later-fourteenth century, but that the door jambs may be thirteenth century. Recent structural analysis by Hill (2007 unpubl) suggests that the rear doorway, which had previously been assumed to be later, has an original lintel, which seems to confirm the cross-passage plan.

The north cross-wing replaced the north end of the fourteenth-century hall range. It included a stone-built parlour on the ground floor, with a fine stone window and beamed ceiling. Above, jettied to both the east and north sides, was a single large timber-framed chamber of three bays, incorporating four trusses consisting of cranked tiebeams with heavy bracing on jowled wall posts, with tenoned purlins and raking struts, and three intermediate trusses consisting of cranked tiebeams, braces, and clasped purlins (Fig 7). The walls were probably of close-studding throughout. It seems likely that there was a stair up to the great chamber in its south-west corner, and a lateral fireplace on its north wall. The south cross-wing also had large chamber on the top floor, but beneath this were a ground and first floor of low height, thought likely to be for service and lower-status use. Although the lower parts of this wing have been much altered, the timber-framed upper storey and roof once again survive in fairly complete state consisting of three bays,
originally comprising four trusses, the fourth westernmost upper roof timbers no longer extant. The trusses consist of a cranked tiebeam on jowled wall posts with principal rafters, clasped purlins, and raking struts (Fig 8). The roofs of the north and south cross-wings are of rather similar type (Figs 7 and 8) leading to the recent suggestion that they may both date to around AD 1500, when major alterations appear to have been carried out (Hill 2007 unpubl). This is however in contrast to the previously postulated interpretation that suggested that the south cross-wing was a later build of seventeenth-century date (Barley 1975).

**SAMPLING**

Sampling and analysis by tree-ring dating of the timbers of Flore’s House were commissioned by English Heritage as part of the dendrochronological training programme of the first author. The purpose of this work was to clarify the date of the hall range and to provide dates for the two cross-wings. It was hoped that this would establish the extent of survival of original timber and elucidate the building’s historic development, hence informing its future management and conservation.

Thus, from the timbers available a total of 58 samples were obtained by coring. Each sample was given the code OKM-A (for Oakham, site ‘A’) and numbered 01–58. The approximate positions of these samples are marked on drawings provided by Nick Hill, these being reproduced here as Figures 9–21. Details of the samples are given in Table 1, in which the timbers have been located and numbered following the scheme on the drawings provided.

No samples were removed from truss 4 in the south cross-wing as, with the exception of the wall posts, the timbers were no longer extant. Sampling in the north cross-wing focused on trusses 6–8 and adjacent bays, as the timbers in truss 5 were believed to have been derived from very fast grown trees, and thus were considered unlikely to provide samples with sufficient rings for reliable analysis. Access to the inserted floor in the hall range was limited, due to modern ceilings covering the earlier timbers, so sampling was restricted to the cross passage and corridor.

**ANALYSIS**

Each of the 58 samples obtained was prepared by sanding and polishing. It was seen at this point that ten samples had an insufficient number of rings required for reliable dating, and so were rejected from this programme of analysis (Table 1). The annual growth rings of the remaining 48 samples were, however, measured, the data of these measurements being given at the end of this report. The data of these 48 samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), allowing, at a minimum value of \( t = 4.4 \), four groups to be formed, the samples of each group cross-matching with each other as shown in the bar diagrams, Figures 22 and 23.
Each site chronology was compared to a full range of reference chronologies for oak, this indicating repeated cross-matches and dates for three of them. The evidence for this dating is given in Tables 2–4. Each site chronology was also compared with the remaining nine ungrouped samples but there was no further satisfactory cross-matching. Each of the remaining nine ungrouped samples was then compared individually with the reference chronologies, but again, there was no satisfactory cross-matching and these samples must, therefore, remain undated.

This analysis can be summarised as follows:

<table>
<thead>
<tr>
<th>Site chronology</th>
<th>Number of samples</th>
<th>Number of rings</th>
<th>Date span (where dated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OKMASQ01</td>
<td>18</td>
<td>220</td>
<td>AD 1173–1392</td>
</tr>
<tr>
<td>OKMASQ02</td>
<td>9</td>
<td>184</td>
<td>AD 1408–1591</td>
</tr>
<tr>
<td>OKMASQ03</td>
<td>10</td>
<td>90</td>
<td>AD 1570–1659</td>
</tr>
<tr>
<td>OKMASQ04</td>
<td>2</td>
<td>81</td>
<td>undated</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>---</td>
<td>undated</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>---</td>
<td>unmeasured</td>
</tr>
</tbody>
</table>

**INTERPRETATION**

**Hall range**

The hall range roof is represented by seven dated samples in site chronology OKMASQ01 (Figs 22 and 24). Two of the samples, OKM–A04 and A10, retain complete sapwood, and were both felled in AD 1378. The heartwood/sapwood boundary is present on only one other sample, OKM–A07. Using the 95% confidence limit of 15–40 sapwood rings appropriate for mature oaks in this part of England, an estimated felling date in the range AD 1370–95 is obtained. This encompasses the precise felling date produced and hence, given that there is no structural evidence to the contrary, it is probable that this timber was also felled in AD 1378. The remaining four dated samples from the hall range roof have no trace of sapwood and it is thus not possible to calculate their likely felling date ranges. However, the dates of their last measured rings range from AD 1317 (A08) to AD 1348 (A06), therefore it is possible that they too were felled in AD 1378. This is supported by the fact that the timbers are integral to the structure, and that there is no evidence for insertion or reuse, as well as by the level of cross-matching within this group.

The lower level of the hall range is also represented by a sample, OKM–A43, in site chronology OKMASQ01, this being from a plate above the east entry to the cross-passage of the hall (Fig 6). This sample also retains the heartwood/sapwood boundary, this being dated to AD 1361. An estimated felling date in the range AD 1376–1401 is obtained, which encompasses the precise felling date obtained for the hall-range roof. It is thus possible that this timber was also cut in AD 1378. Given that it is not directly
associated with the roof structure, this is less certain, though it is clearly broadly coeval with the dated roof timbers.

The inserted floor of the hall range is represented by nine dated samples in site chronology OKMASQ02 (Figs 22 and 24). Eight were from the ceiling and one from the front east wall post, which is structurally integral to the ceiling. One of these samples, OKM–A48, retains complete sapwood and was felled in AD 1591. The relative position of the heartwood/sapwood boundary on four other samples is very similar, again suggesting a single phase of felling, and it is probable that these four timbers were felled in AD 1591 as well. The remaining four dated samples from the inserted floor do not have the heartwood/sapwood boundary and it is not possible to calculate their likely felling date ranges. However, the dates of their last measured rings range from AD 1517 (A44) to AD 1543 (A41). It is therefore possible that they too were felled in AD 1591 since, in addition to the level of cross-matching within this group, they are again integral to the structure and there is no evidence for insertion or reuse.

**North cross-wing**

The north cross-wing roof is represented by ten dated samples in site chronology OKMASQ03 (Figs 22 and 24). One of these samples, OKM-A34, retains complete sapwood, thus the felling of the timber is dated to AD 1659. Six other samples have retained the heartwood/sapwood boundaries, which again, with a variation of only 12 years between them, suggest a single phase of felling. It is thus probable that these timbers were also felled in AD 1659. The remaining three dated timbers cross-match well within the group and there is no evidence, in the form of possible insertion or reuse, to indicate that these timbers were not also felled in AD 1659 as well since their last measured ring dates range from AD 1619 (A56) to AD 1631 (A50).

**South cross-wing**

The south cross-wing is represented by 10 dated samples in site chronology OKMASQ01 (Figs 22 and 24). Four of these samples retain some trace of sapwood. The heartwood/sapwood boundaries date to within five years of each other, thus being indicative of timbers representing a single felling phase. The average date of the heartwood/sapwood boundary on these samples is AD 1386 which, using the same sapwood estimate as above, would give an estimated felling date in the range AD 1401–26. However, this estimated felling date range can be refined as the outermost approximately 15 mm of sapwood, complete to the bark edge, was lost during coring from sample OKM–A25, due to its fragile nature. It was noted at the time of sampling that this loss represents between approximately 15 and 18 rings. Given that the last sapwood ring on sample OKM–A25 is dated to AD 1392, such a loss would indicate that this timber, and hence the other three as well, was felled in the range *circa* AD 1407–10.
The remaining six dated samples from the south cross-wing do not have heartwood/sapwood boundaries present and it is thus not possible to calculate their likely felling date ranges. However, with last measured ring dates ranging from AD 1324 (A22) to AD 1380, and bearing in mind the level of cross-matching within this group, it is possible that they too were felled in *circa* AD 1407-10. This is supported by the fact that once again the timbers are integral, and that there is no evidence for insertion or reuse.

**DISCUSSION**

Though it had previously been suggested that the stone door jambs in the hall may be of thirteenth-century date (Pevsner 1974; Barley 1975), no timbers this early were found during this programme of tree-ring dating. The earliest extant timbers at Flore’s House to be dated by tree-ring analysis are those from the hall range roof, which were felled in AD 1378. The plate above the east entry to the cross-passage of the hall dates to the late-fourteenth century, and may well be coeval with the hall range roof. These results therefore suggest that the most likely candidate for undertaking this work is William Flore, rather than his son Roger, as he was controller of the works at Oakham Castle at this time. A further phase of work is indicated in the hall range, where a floor and an associated post were inserted using timbers felled in AD 1591.

The south cross-wing contains a series of timbers felled in *circa* AD 1407–10, which suggests a somewhat earlier date of construction than expected, only approximately 30 years after the major works in the hall range. Roger Flore’s political career was ascending during these years (Roskell 1957), so it appears that he would have been in a financial position to commission such building work, though it is possible that his father, William, was still alive at this point and that he sanctioned the work.

The north cross-wing roof is constructed of timbers felled in AD 1659. It has previously been thought to be broadly coeval with that of the south cross-wing, due to its similar stylistic features. These seventeenth-century timbers suggest that further reappraisal of the structural evidence is needed, in order to clarify whether these represent a replacement roof inserted during major works on the original building, or whether they represent the construction of the north cross-wing. It should be noted here that there may be additional timbers that are suitable for dendrochronological analysis from the lower levels of the north cross-wing. Unfortunately, at the time of sampling these were either concealed by modern office fittings and equipment, or were inaccessible due to the presence of a busy café. Clearly if access issues can be resolved in the future, it would be worth assessing the timbers as to their suitability for tree-ring sampling, as they may have the potential to aid the understanding of this north cross-wing.

A number of noticeably high $t$-values, identified during cross-matching, combined with the conversion method for the timbers from which these cores were taken, suggest the possibility that some timbers are derived from the same tree. These comprise: OKM–A06/A12 ($t=12.9$) from the hall range roof; OKM–A27/A31 ($t=11.9$) and OKM–A28/A35
(t=11.0) from the north cross-wing roof; OKM–A41/A45 (t=12.6), OKM–A45/A48 (t=11.1) and OKM–A41/A48 from the inserted ceiling in the hall range, all three of which are likely to be derived from the same tree. The intra-phase cross-matching for the inserted ceiling timbers is particularly high, which strongly suggests that this group of material is derived from a single woodland source. However, the inter-phase cross-matching between the late fourteenth-century samples from the hall range and the early fifteenth-century samples from the south cross-wing is slightly poorer, as they come together with a minimum value of t=4.4. This suggests that these two broadly coeval groups of timber may come from slightly different woodland sources.

Although dendrochronology cannot be used to identify the precise source of timber (e.g. Bridge 2000), it would appear that the timbers analysed from Flore’s House are likely to be derived from woodlands that were reasonably local to Oakham. As will be seen from Tables 2–4, many of the highest t-values, and thus the greatest degree of similarity, obtained during the dating of the three site sequences are with reference chronologies from sites elsewhere in the East Midlands region.

Of the 48 samples which were measured, nine remain ungrouped and undated. Most of these ungrouped samples have ring numbers which are close to the lower limit of statistical reliability; only a few have higher numbers. None of these samples have obvious growth abnormalities, such as distortion or compression of the rings, which would make cross-matching and dating difficult. It is possible that the undated timbers are from different woodland sources, making them, in effect ‘singletons’. Such samples are often more difficult to date than longer well-replicated site chronologies. There were however noticeable growth abnormalities with a number of the samples from the north cross-wing roof. The inner rings on cores OKM–A27, A34, A36, A50 and A56 were excluded from the analysis due to distortion of their rings which clearly hampered overall cross-matching between the individuals.
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### Table 1: Details of samples from Flore’s House, Oakham, Rutland

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Sample location</th>
<th>Total rings</th>
<th>Sapwood Rings</th>
<th>First measured ring date</th>
<th>Last heartwood ring date</th>
<th>Last measured ring date</th>
</tr>
</thead>
<tbody>
<tr>
<td>OKM-A01</td>
<td>Crown post, truss A</td>
<td>156</td>
<td>no h/s</td>
<td>AD 1173</td>
<td>AD 1328</td>
<td></td>
</tr>
<tr>
<td>OKM-A02</td>
<td>S brace truss A to crown plate</td>
<td>53</td>
<td>no h/s</td>
<td>-----</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>OKM-A03</td>
<td>N brace truss B to crown plate</td>
<td>77</td>
<td>no h/s</td>
<td>-----</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>OKM-A04</td>
<td>S brace truss B to crown plate</td>
<td>71</td>
<td>33C</td>
<td>AD 1308</td>
<td>AD 1345</td>
<td>AD 1378</td>
</tr>
<tr>
<td>OKM-A05</td>
<td>E brace, crown post to collar, truss B</td>
<td>nm</td>
<td>---</td>
<td>-----</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>OKM-A06</td>
<td>N brace truss C to crown plate</td>
<td>161</td>
<td>no h/s</td>
<td>AD 1188</td>
<td>AD 1348</td>
<td></td>
</tr>
<tr>
<td>OKM-A07</td>
<td>E arch brace, truss C</td>
<td>183</td>
<td>11</td>
<td>AD 1184</td>
<td>AD 1355</td>
<td>AD 1366</td>
</tr>
<tr>
<td>OKM-A08</td>
<td>E spandrel strut, truss C</td>
<td>93</td>
<td>no h/s</td>
<td>AD 1225</td>
<td>AD 1317</td>
<td></td>
</tr>
<tr>
<td>OKM-A09</td>
<td>W brace, crown post to collar, truss D</td>
<td>70</td>
<td>no h/s</td>
<td>-----</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>OKM-A10</td>
<td>E wall plate, truss C – D</td>
<td>104</td>
<td>22C</td>
<td>AD 1275</td>
<td>AD 1356</td>
<td>AD 1378</td>
</tr>
<tr>
<td>OKM-A11</td>
<td>Tiebeam, truss D</td>
<td>nm</td>
<td>---</td>
<td>-----</td>
<td>-----</td>
<td></td>
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<tr>
<td>OKM-A12</td>
<td>W arch brace truss D</td>
<td>132</td>
<td>no h/s</td>
<td>AD 1215</td>
<td>AD 1346</td>
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<tr>
<td>OKM-A13</td>
<td>N wall post, truss 1</td>
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<td>no h/s</td>
<td>AD 1236</td>
<td>AD 1380</td>
<td></td>
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<tr>
<td>OKM-A14</td>
<td>North principal rafter, truss 1</td>
<td>63</td>
<td>no h/s</td>
<td>-----</td>
<td>-----</td>
<td></td>
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<tr>
<td>OKM-A15</td>
<td>Tiebeam, truss 1</td>
<td>123</td>
<td>3</td>
<td>AD 1268</td>
<td>AD 1387</td>
<td>AD 1390</td>
</tr>
<tr>
<td>OKM-A16</td>
<td>S common rafter 2, bay 1</td>
<td>55</td>
<td>12</td>
<td>-----</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>OKM-A17</td>
<td>Stud post 5, south wall, bay 1</td>
<td>58</td>
<td>no h/s</td>
<td>-----</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>OKM-A18</td>
<td>N wall post, truss 2</td>
<td>59</td>
<td>h/s</td>
<td>AD 1324</td>
<td>AD 1382</td>
<td>AD 1382</td>
</tr>
<tr>
<td>OKM-A19</td>
<td>Tiebeam, truss 2</td>
<td>189</td>
<td>no h/s</td>
<td>AD 1191</td>
<td>AD 1379</td>
<td></td>
</tr>
<tr>
<td>OKM-A20</td>
<td>N principal rafter, truss 2</td>
<td>53</td>
<td>hs</td>
<td>-----</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>OKM-A21</td>
<td>N common rafter 1, bay 2</td>
<td>68</td>
<td>h/s</td>
<td>AD 1320</td>
<td>AD 1387</td>
<td>AD 1387</td>
</tr>
<tr>
<td>OKM-A22</td>
<td>Stud post 1, south wall, bay 2</td>
<td>140</td>
<td>no h/s</td>
<td>AD 1185</td>
<td>AD 1324</td>
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</tr>
<tr>
<td>OKM-A23</td>
<td>Stud post 3, south wall, bay 2</td>
<td>96</td>
<td>no h/s</td>
<td>AD 1282</td>
<td>AD 1377</td>
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<tr>
<td>OKM-A24</td>
<td>Stud post 4, south wall, bay 2</td>
<td>107</td>
<td>no h/s</td>
<td>AD 1240</td>
<td>AD 1346</td>
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</tr>
<tr>
<td>OKM-A25</td>
<td>Tiebeam, truss 3</td>
<td>176</td>
<td>5c*</td>
<td>AD 1217</td>
<td>AD 1387</td>
<td>AD 1392</td>
</tr>
<tr>
<td>OKM-A26</td>
<td>South wall post, truss 3</td>
<td>80</td>
<td>no h/s</td>
<td>AD 1259</td>
<td>AD 1338</td>
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</tr>
<tr>
<td>OKM-A27</td>
<td>S strut, truss 7</td>
<td>77</td>
<td>h/s</td>
<td>AD 1570</td>
<td>AD 1646</td>
<td>AD 1646</td>
</tr>
<tr>
<td>OKM-A28</td>
<td>Stud post 6 from N, truss 5 (E gable)</td>
<td>49</td>
<td>h/s</td>
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<tr>
<td>OKM-A29</td>
<td>Intermediate collar, bay 1</td>
<td>63</td>
<td>no h/s</td>
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<td>OKM-A30</td>
<td>S common rafter 3, bay 1</td>
<td>nm</td>
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<td></td>
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<tr>
<td>OKM-A31</td>
<td>N strut, truss 6</td>
<td>73</td>
<td>6</td>
<td>AD 1579</td>
<td>AD 1645</td>
<td>AD 1651</td>
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<tr>
<td>OKM-A32</td>
<td>Tiebeam, truss 6</td>
<td>74</td>
<td>h/s</td>
<td>-----</td>
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</tr>
<tr>
<td>OKM-A33</td>
<td>N common rafter 3, bay 2</td>
<td>nm</td>
<td>---</td>
<td>-----</td>
<td>-----</td>
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<tr>
<td>OKM-A34</td>
<td>N strut, truss 7</td>
<td>89</td>
<td>18C</td>
<td>AD 1571</td>
<td>AD 1641</td>
<td>AD 1659</td>
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<td>OKM-A35</td>
<td>Tiebeam, truss 7</td>
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<td>h/s</td>
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<td>Sample number</td>
<td>Sample location</td>
<td>Total rings</td>
<td>Sapwood Rings</td>
<td>First measured ring date</td>
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<td>Last measured ring date</td>
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<td>---------------</td>
<td>-----------------</td>
<td>-------------</td>
<td>---------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>------------------------</td>
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<tr>
<td>OKM-A36</td>
<td>SW windbrace, truss 7</td>
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<td>no h/s</td>
<td>AD 1570</td>
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<td>AD 1626</td>
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<td>OKM-A38</td>
<td>Intermediate collar, bay 3</td>
<td>nm</td>
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<td></td>
<td>Hall range inserted ceiling and ground floor timbers</td>
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</tr>
<tr>
<td>OKM-A39</td>
<td>Joist 1</td>
<td>96</td>
<td>no h/s</td>
<td>AD 1427</td>
<td>------</td>
<td>AD 1522</td>
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<td>OKM-A40</td>
<td>Joist 2</td>
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<td>AD 1518</td>
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<td>OKM-A41</td>
<td>Joist 3</td>
<td>84</td>
<td>no h/s</td>
<td>AD 1460</td>
<td>------</td>
<td>AD 1543</td>
</tr>
<tr>
<td>OKM-A42</td>
<td>Front (E) wall post, adj to arch brace Truss B</td>
<td>93</td>
<td>h/s</td>
<td>AD 1477</td>
<td>AD 1569</td>
<td>AD 1569</td>
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<tr>
<td>OKM-A43</td>
<td>Front plate over E cross-passage door</td>
<td>151</td>
<td>h/s</td>
<td>AD 1211</td>
<td>AD 1361</td>
<td>AD 1361</td>
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<tr>
<td>OKM-A44</td>
<td>Joist 8</td>
<td>80</td>
<td>no h/s</td>
<td>AD 1438</td>
<td>------</td>
<td>AD 1517</td>
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<tr>
<td>OKM-A45</td>
<td>Joist 9</td>
<td>86</td>
<td>h/s</td>
<td>AD 1483</td>
<td>AD 1568</td>
<td>AD 1568</td>
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<td>OKM-A46</td>
<td>Joist 10</td>
<td>105</td>
<td>18</td>
<td>AD 1485</td>
<td>AD 1571</td>
<td>AD 1589</td>
</tr>
<tr>
<td>OKM-A47</td>
<td>Joist 11</td>
<td>94</td>
<td>h/s</td>
<td>AD 1477</td>
<td>AD 1570</td>
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<tr>
<td>OKM-A48</td>
<td>Main central spine beam</td>
<td>129</td>
<td>32C</td>
<td>AD 1463</td>
<td>AD 1559</td>
<td>AD 1591</td>
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<td>North cross-wing roof (contd)</td>
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<tr>
<td>OKM-A49</td>
<td>NE windbrace, truss 6</td>
<td>55</td>
<td>h/s</td>
<td>AD 1581</td>
<td>AD 1635</td>
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<tr>
<td>OKM-A50</td>
<td>NW windbrace, truss 6</td>
<td>62</td>
<td>no h/s</td>
<td>AD 1570</td>
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<td>AD 1631</td>
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<tr>
<td>OKM-A51</td>
<td>S strut, truss 6</td>
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<td>h/s</td>
<td>AD 1573</td>
<td>AD 1641</td>
<td>AD 1641</td>
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<tr>
<td>OKM-A52</td>
<td>SE windbrace, truss 6</td>
<td>61</td>
<td>h/s</td>
<td>AD 1573</td>
<td>AD 1633</td>
<td>AD 1633</td>
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<tr>
<td>OKM-A53</td>
<td>SW windbrace, truss 6</td>
<td>nm</td>
<td>---</td>
<td>------</td>
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<td>------</td>
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<tr>
<td>OKM-A54</td>
<td>NE windbrace, truss 7</td>
<td>54</td>
<td>h/s</td>
<td>AD 1585</td>
<td>AD 1638</td>
<td>AD 1638</td>
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<tr>
<td>OKM-A55</td>
<td>SE windbrace, truss 7</td>
<td>nm</td>
<td>---</td>
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<td>------</td>
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<tr>
<td>OKM-A56</td>
<td>N strut, truss 8</td>
<td>50</td>
<td>no h/s</td>
<td>AD 1570</td>
<td>------</td>
<td>AD 1619</td>
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<tr>
<td>OKM-A57</td>
<td>S strut, truss 8</td>
<td>nm</td>
<td>---</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>OKM-A58</td>
<td>SE brace, truss 8</td>
<td>nm</td>
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*h/s = heartwood/sapwood boundary
C = complete sapwood is retained on the sample, the last measured ring date is the felling date of the timber
nm = sample not measured
* - sample OKM-A25 had complete sapwood to bark edge on the timber, but the outermost approximately 15–18 rings were lost during coring
Table 2: Results of the cross-matching of site chronology OKMASQ01 and relevant reference chronologies when first ring date is AD 1173 and last ring date is AD 1392

<table>
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<tr>
<th>Reference chronology</th>
<th>Span of chronology</th>
<th>t-value</th>
<th>Reference source</th>
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<tr>
<td>East Midlands Master Chronology</td>
<td>AD 882–1981</td>
<td>13.7</td>
<td>(Laxton and Litton 1988)</td>
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<tr>
<td>Ulverscroft Priory, Charnwood, Leicestershire</td>
<td>AD 1219–1461</td>
<td>12.3</td>
<td>(Arnold et al 2008)</td>
</tr>
<tr>
<td>College House, Oakham School, Oakham, Rutland</td>
<td>AD 1172–1307</td>
<td>10.1</td>
<td>(Howard et al 1999)</td>
</tr>
<tr>
<td>Cross Keys Inn, Leicester</td>
<td>AD 1104–1309</td>
<td>8.7</td>
<td>(Howard et al 1988)</td>
</tr>
<tr>
<td>Braunston, Leicestershire</td>
<td>AD 1165–1279</td>
<td>8.7</td>
<td>(Laxton et al 1984)</td>
</tr>
<tr>
<td>Glenfield well, Glenfield, Leicestershire</td>
<td>AD 1182–1393</td>
<td>8.3</td>
<td>(Howard et al 1985)</td>
</tr>
<tr>
<td>Wymondley Bury, Little Wymondley, Hertfordshire</td>
<td>AD 1184–1379</td>
<td>8.4</td>
<td>(Groves et al 2005)</td>
</tr>
<tr>
<td>Sinai Park, Burton, Staffordshire</td>
<td>AD 1227–1750</td>
<td>8.1</td>
<td>(Tyers 1997)</td>
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Table 3: Results of the cross-matching of site chronology OKMASQ02 and relevant reference chronologies when first ring date is AD 1408 and last ring date is AD 1591

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<td>10.2</td>
<td>(Laxton and Litton 1988)</td>
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<tr>
<td>Nevill Holt, Leicestershire</td>
<td>AD 1274–1534</td>
<td>9.9</td>
<td>(Howard 2001 unpubl)</td>
</tr>
<tr>
<td>St Andrews Church, Wimpole, Cambridgeshire</td>
<td>AD 1469–1615</td>
<td>9.1</td>
<td>(Bridge 1998)</td>
</tr>
<tr>
<td>Kingsbury Hall, Kingsbury, Warwickshire</td>
<td>AD 1391–1564</td>
<td>9.6</td>
<td>(Arnold and Howard 2006)</td>
</tr>
<tr>
<td>Church of St Nicholas, Bringham, Leicestershire</td>
<td>AD 1502–1687</td>
<td>9.4</td>
<td>(Arnold et al 2005)</td>
</tr>
<tr>
<td>Sinai Park, Burton, Staffordshire</td>
<td>AD 1227–1750</td>
<td>9.2</td>
<td>(Tyers 1997)</td>
</tr>
<tr>
<td>St Stephen's Church, Sneinton, Nottingham</td>
<td>AD 1484–1654</td>
<td>8.8</td>
<td>(Arnold and Howard 2006 unpubl)</td>
</tr>
<tr>
<td>Lowdham Old Hall (barn), Lowdham, Nottinghamshire</td>
<td>AD 1422–1527</td>
<td>8.7</td>
<td>(Howard et al 1997)</td>
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Table 4: Results of the cross-matching of site chronology OKMASQ03 and relevant reference chronologies when first ring date is AD 1570 and last ring date is AD 1659

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<th>t-value</th>
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</thead>
<tbody>
<tr>
<td>England mid-west regional</td>
<td>AD 860–1790</td>
<td>5.9</td>
<td>(Tyers pers comm)</td>
</tr>
<tr>
<td>Lodge Farm, Staunton Harold, Leicestershire</td>
<td>AD 1533–1647</td>
<td>5.8</td>
<td>(Arnold and Howard 2007a unpubl)</td>
</tr>
<tr>
<td>15/17 St John's St, Wirksworth, Derbyshire</td>
<td>AD 1586–1676</td>
<td>5.7</td>
<td>(Howard et al 1995)</td>
</tr>
<tr>
<td>England mid-east regional</td>
<td>AD 947–1805</td>
<td>5.7</td>
<td>(Tyers pers comm)</td>
</tr>
<tr>
<td>Black Ladies, Brewood, Staffordshire</td>
<td>AD 1372–1671</td>
<td>5.4</td>
<td>(Tyers 1999a)</td>
</tr>
<tr>
<td>Bell Tower, Pembridge, Herefordshire</td>
<td>AD 1559–1668</td>
<td>5.4</td>
<td>(Tyers 1999b)</td>
</tr>
<tr>
<td>King's Manor, York, North Yorkshire</td>
<td>AD 1361–1667</td>
<td>5.2</td>
<td>(King pers comm)</td>
</tr>
</tbody>
</table>
Figure 1: Map to show general location of Flore’s House (based on the Ordnance Survey map with permission of the Controller of Her Majesty’s Stationery Office, © Crown Copyright)
Figure 2: Map to show the location of Flore’s House (based on the Ordnance Survey map with permission of the Controller of Her Majesty’s Stationery Office, © Crown Copyright)
Figure 3: Flore’s House looking south west

Figure 4: Flore’s House ground floor plan (based on a drawing by M W Barley 1975)
Figure 5: The hall range roof truss B viewed from truss C looking north-west

Figure 6: General view of the cross passage looking east towards the front door
Figure 7: North cross-wing truss 7 viewed looking west

Figure 8: South cross-wing truss 2 looking south-east
Figure 9: Upper floor plan showing location of samples not shown on the elevation and sections below (based on a drawing provided by N Hill)
Figure 10: Ground floor plan showing sample locations (based on a drawing by M W Barley 1975)
Figure 11: East elevation showing sample locations (based on a drawing provided by N Hill)
Figure 12: Hall range truss A showing sample location viewed from the south looking north (based on a drawing by M W Barley 1975)

Figure 13: Hall range truss C showing sample locations viewed from the north looking south (based on a drawing provided by N Hill)
Figure 14: Hall range truss D showing sample locations, viewed looking north to south (based on a drawing by M W Barley 1975)

Figure 15: South cross-wing truss 2 showing sample locations, viewed from the east looking west (based on a drawing provided by N Hill)
Figure 16: South cross-wing truss 3 showing sample locations, viewed from the east looking west (based on a drawing provided by N Hill)

Figure 17: North cross-wing truss 6 showing sample locations, viewed from east looking west (based on drawings provided by N Hill)
Figure 18: North cross-wing truss 7 showing sample locations, viewed from east looking west (based on drawings provided by N Hill)

Figure 19: North cross-wing truss 8 showing sample locations, viewed from east looking west (based on drawings provided by N Hill)
Figure 20: North cross-wing intermediate truss bay 3 showing sample location viewed from the east looking west (based on drawings provided by N Hill)

Figure 21: North cross-wing intermediate truss bay 1 showing sample location viewed from the east looking west (based on drawings provided by N Hill)
Figure 22: Bar diagram of the samples in site chronologies OKMASQ01, OKMASQ02 and OKMASQ03
White bars = heartwood rings
h/s = the last ring of the sample is at the heartwood/sapwood boundary

Figure 23: Bar diagram of the samples in site chronology OKMASQ04
Figure 24: Bar diagrams sorted by area group
### DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

| OKM-A01A 156 | 322 314 325 375 325 222 197 206 277 295 279 198 269 219 176 70 127 180 141 179 120 117 88 98 94 61 73 46 38 34 31 38 33 38 39 61 68 51 55 64 79 61 73 44 65 76 54 34 55 28 40 32 40 37 46 36 31 42 66 67 84 75 104 64 84 57 80 155 172 163 81 76 100 85 96 147 192 170 137 82 |

| OKM-A01B 156 | 347 312 304 353 320 233 190 195 271 303 279 205 275 221 172 76 115 186 140 181 221 198 210 189 163 185 314 231 220 194 148 122 115 86 62 49 36 55 105 126 128 100 89 96 98 58 77 47 31 32 29 38 40 25 46 57 58 58 48 70 74 66 76 46 63 66 60 44 40 37 45 30 33 46 43 34 29 43 68 67 81 79 100 67 84 62 71 136 162 161 76 77 88 95 92 141 180 167 136 89 95 74 73 85 89 102 56 171 248 187 180 182 137 124 129 235 198 146 114 110 90 82 65 75 102 90 92 111 92 96 105 99 72 112 71 81 58 37 44 40 41 49 37 40 34 42 31 32 45 49 49 48 44 52 58 74 |


| OKM-A04A 71 | 88 67 69 62 89 66 75 143 170 125 109 98 88 83 87 111 114 92 84 144 142 140 184 124 215 214 120 152 106 99 132 134 155 189 183 189 143 109 113 110 142 147 148 186 117 174 124 100 76 82 38 46 69 100 146 87 111 93 60 59 |
46 80 84 101 91 86 98 59 95
OKM-A48B 129
306 268 169 134 98 117 136 162 164 130 130 150 182 209 189 219 233 263 257 253
170 112 125 139 211 155 187 152 181 189 229 144 153 120 205 170
183 171 163 122 175 118 152 163 168 169 179 150 127 139 143 72 95 139 120 97
112 112 158 81 110 113 103 122 104 136 87 99 93 114 83 69 94 76 66 71 74
100 80 95 92 49 92 85 58 81 62 71 49 78 60 49 56 59 39 60 62
54 47 51 35 39 40 51 45 48 29 35 31 37 49 59 44 62 70 65 65
50 77 93 99 80 92 83 66 98
OKM-A49A 55
158 178 174 208 166 220 132 145 206 188 187 207 191 193 261 203 153 191 185
206 286 283 350 295 201 198 203 235 165 143 203 209 262 228 199 159 160 224 216
209 158 232 159 125 185 217 227 226 198 207 167 192 149 127 176
OKM-A49B 55
160 180 154 164 177 205 127 158 199 199 204 220 197 263 200 159 191 200
192 289 288 359 248 209 200 198 227 158 143 204 210 267 233 208 169 166 231 226
197 172 236 164 111 188 204 225 227 196 205 165 188 142 110 175
OKM-A50A 62
207 169 140 206 133 98 131 185 194 254 157 151 164 136 179 234 254 132 128 217
164 199 237 166 196 272 114 131 217 198 157 242 197 279 196 187 166 194 228
110 99 159 218 213 193 149 129 158 170 142 115 100 165 100 98 150 120 149 156
135 163 126
OKM-A50B 62
198 169 154 192 141 95 124 175 192 248 143 159 155 144 173 234 242 134 124 207
168 210 230 188 188 270 125 134 198 172 152 226 205 272 214 182 174 179 210
111 106 174 218 214 180 161 123 165 158 142 117 110 168 102 87 137 129 137 155
147 162 125
OKM-A51A 68
459 440 411 330 425 341 492 499 523 470 281 300 340 252 145 159 254 276 257
330 359 396 535 351 256 214 223 179 217 144 239 231 88 118 251 226 154 188 131
268 231 269 143 136 162 288 238 218 175 177 237 131 107 72 157 168 190 182 126
136 103 101 142 110 169 170 80 145
OKM-A51B 69
482 438 464 371 417 346 498 511 548 541 461 300 302 326 271 164 146 246 269 251
331 341 410 515 365 256 178 235 184 212 140 247 234 88 109 231 216 153 209 131
259 248 261 147 133 171 299 244 218 159 181 226 134 105 78 160 167 191 183 134
135 109 92 143 104 165 172 79 160 190
OKM-A52A 61
114 89 94 114 127 178 185 179 214 245 196 277 208 288 133 112 167 199 248 265
224 327 345 211 187 247 213 234 343 287 368 356 217 244 265 270 198 139 204
251 255 238 231 240 267 297 285 260 208 235 206 147 176 163 172 203 244 202 177
216 173
OKM-A52B 61
195 81 90 115 122 168 177 170 210 251 221 299 202 279 168 135 185 198 238 261

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Appendix: Tree-Ring Dating

The Principles of Tree-Ring Dating

Tree-ring dating, or dendrochronology as it is known, is discussed in some detail in the Laboratory’s Monograph, An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building (Laxton and Litton 1988) and Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates (English Heritage 1988). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The width of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure A1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of oak timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

If the bark is still on the sample, as in Figure A1, then the date of the last ring will be the date of felling of the oak from which it was cut. There is much evidence that in medieval times oaks cut down for building purposes were used almost immediately, usually within the year or so (Rackham 1976). Hence if bark is present on several main timbers in a building, none of which appear reused or are later insertions, and if they all have the same date for their last ring, then we can be quite confident that this is the date of construction or soon after. If there is no bark on the sample, then we have to make an estimate of the felling date; how this is done is explained below.

The Practice of Tree-Ring Dating at the Nottingham Tree-Ring Dating Laboratory

1. Inspecting the Building and Sampling the Timbers. Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample in situ timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique
position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure A2 has about 120 rings; about 20 of which are sapwood rings – the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood rings.

To ensure that we are getting the date of the building as a whole, or the whole of a phase of construction if there is more than one, about 8–10 samples per phase are usually taken. Sometimes we take many more, especially if the construction is complicated. One reason for taking so many samples is that, in general, some will fail to give a date. There may be many reasons why a particular sequence of ring widths from a sample of timber fails to give a date even though others from the same building do. For example, a particular tree may have grown in an odd ecological niche, so odd indeed that the widths of its rings were determined by factors other than the local climate! In such circumstances it will be impossible to date a timber from this tree using the master sequence whose widths, we can assume, were predominantly determined by the local climate at the time.

Sampling is done by coring into the timber with a hollow corer attached to an electric drill and usually from its outer rings inwards towards where the centre of the tree, the pith, is judged to be. An illustration of a core is shown in Figure A2; it is about 150mm long and 10mm diameter. Great care has to be taken to ensure that as few as possible of the outer rings are lost in coring. This can be difficult as these outer rings are often very soft (see below on sapwood). Each sample is given a code which identifies uniquely which timber it comes from, which building it is from and where the building is located. For example, CRO-A06 is the sixth core taken from the first building (A) sampled by the Laboratory in Cropwell Bishop. Where it came from in that building will be shown in the sampling records and drawings. No structural damage is done to any timbers by coring, nor does it weaken them.

During the initial inspection of the building and its timbers the dendrochronologist may come to the conclusion that, as far as can be judged, none of the timbers have sufficient rings in them for dating purposes and may advise against sampling to save further unwarranted expense.

All sampling by the Laboratory is undertaken according to current Health and Safety Standards. The Laboratory’s dendrochronologists are insured.
Figure A1: A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring which grew in 1976.
Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

Figure A3: Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis.
Figure A4: Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.
2. **Measuring Ring Widths.** Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure A2. The core is then mounted on a movable table below a microscope and the ring-widths measured individually from the innermost ring to the outermost. The widths are automatically recorded in a computer file as they are measured (see Fig A3).

3. **Cross-Matching and Dating the Samples.** Because of the factors besides the local climate which may determine the annual widths of a tree’s rings, no two sequences of ring widths from different oaks growing at the same time are exactly alike (Fig A4). Indeed, the sequences may not be exactly alike even when the trees are growing near to each other. Consequently, in the Laboratory we do not attempt to match two sequences of ring widths by eye, or graphically, or by any other subjective method. Instead, it is done objectively (i.e. statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the $t$-value (defined in almost any introductory book on statistics). That offset with the maximum $t$-value among the $t$-values at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a $t$-value of at least 4.5, and preferably at least 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton and Litton 1988; Laxton et al 1988; Howard et al 1984–1995).

This is illustrated in Figure A5 with timbers from one of the roofs of Lincoln Cathedral. Here four sequences of ring widths, LIN-C04, 05, 08, and 45, have been cross-matched with each other. The ring widths themselves have been omitted in the bar diagram, as is usual, but the offsets at which they best cross-match each other are shown; eg the sequence of ring widths of C08 matches the sequence of ring widths of C45 best when it is at a position starting 20 rings after the first ring of C45, and similarly for the others. The actual $t$-values between the four at these offsets of best correlations are in the matrix. Thus at the offset of +20 rings, the $t$-value between C45 and C08 is 5.6 and is the maximum found between these two among all the positions of one sequence relative to the other.

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Figure A5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in Fig A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site
sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

The straightforward method of cross-matching several sample sequences with each other one at a time is called the ‘maximal t-value’ method. The actual method of cross-matching a group of sequences of ring-widths used in the Laboratory involves grouping and averaging the ring-width sequences and is called the ‘Litton-Zainodin Grouping Procedure’. It is a modification of the straightforward method and was successfully developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton et al 1988).

4. Estimating the Felling Date. As mentioned above, if the bark is present on a sample, then the date of its last ring is the date of the felling of its tree (or the last full year before felling, if it was felled in the first three months of the following calendar year, before any new growth had started, but this is not too important a consideration in most cases). The actual bark may not be present on a timber in a building, though the dendrochronologist who is sampling can often see from its surface that only the bark is missing. In these cases the date of the last ring is still the date of felling.

Quite often some, though not all, of the original outer rings are missing on a timber. The outer rings on an oak, called sapwood rings, are usually lighter than the inner rings, the heartwood, and so are relatively easy to identify. For example, sapwood can be seen in the corner of the rafter and at the outer end of the core in Figure A2, both indicated by arrows. More importantly for dendrochronology, the sapwood is relatively soft and so liable to insect attack and wear and tear. The builder, therefore, may remove some of the sapwood for precisely these reasons. Nevertheless, if at least some of the sapwood rings are left on a sample, we will know that not too many rings have been lost since felling so that the date of the last ring on the sample is only a few years before the date of the original last ring on the tree, and so to the date of felling.

Various estimates have been made and used for the average number of sapwood rings in mature oak trees (English Heritage 1998). A fairly conservative range is between 15 and 50 and that this holds for 95% of mature oaks. This means, of course, that in a small number of cases there could be fewer than 15 and more than 50 sapwood rings. For example, the core CRO-A06 has only 9 sapwood rings and some have obviously been lost over time – either they were removed originally by the carpenter and/or they rotted away in the building and/or they were lost in the coring. It is not known exactly how many sapwood rings are missing, but using the above range the Laboratory would estimate between a minimum of 6 (=15-9) and a maximum of 41 (=50-9). If the last ring of CRO-A06 has been dated to 1500, say, then the estimated felling-date range for the tree from which it came originally would be between 1506 and 1541. The Laboratory uses this estimate for sapwood in areas of England where it has no prior information. It
also uses it when dealing with samples with very many rings, about 120 to the last heartwood ring. But in other areas of England where the Laboratory has accumulated a number of samples with complete sapwood, that is, no sapwood lost since felling, other estimates in place of the conservative range of 15 to 50 are used. In the East Midlands (Laxton et al 2001) and the east to the south down to Kent (Pearson 1995) where it has sampled extensively in the past, the Laboratory uses the shorter estimate of 15 to 35 sapwood rings in 95% of mature oaks growing in these parts. Since the sample CRO-A06 comes from a house in Cropwell Bishop in the East Midlands, a better estimate of sapwood rings lost since felling is between a minimum of 6 (=15-9) and 26 (=35-9) and the felling would be estimated to have taken place between 1506 and 1526, a shorter period than before. Oak boards quite often come from the Baltic region and in these cases the 95% confidence limits for sapwood are 9 to 36 (Howard et al 1992, 56).

Even more precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure A2 was taken still had complete sapwood but that some of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 20mm, a reasonable estimate can be made of the number of sapwood rings lost, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 35 years later we would have estimated without this observation. In the example, the felling is now estimated to have taken place between AD 1512 and 1515, which is much more precise than without this extra information.

Even if all the sapwood rings are missing on a sample, but none of the heartwood rings are, then an estimate of the felling-date range is possible by adding on the full compliment of, say, 15 to 35 years to the date of the last heartwood ring (called the heartwood/sapwood boundary or transition ring and denoted H/S). Fortunately it is often easy for a trained dendrochronologist to identify this boundary on a timber. If a timber does not have its heartwood/sapwood boundary, then only a post quem date for felling is possible.

**5. Estimating the Date of Construction.** There is a considerable body of evidence collected by dendrochronologists over the years that oak timbers used in buildings were not seasoned in medieval or early modern times (English Heritage 1998; Miles 1997, 50–5). Hence, provided that all the samples in a building have estimated felling-date ranges broadly in agreement with each other, so that they appear to have been felled as a group, then this should give an accurate estimate of the period when the structure was built, or soon after (Laxton et al 2001, fig 8; 34–5, where ‘associated groups of fellings’ are discussed in detail). However, if there is any evidence of storage before use, or if there is evidence the oak came from abroad (eg Baltic boards), then some allowance has to be made for this.
6. Master Chronological Sequences. Ultimately, to date a sequence of ring widths, or a site sequence, we need a master sequence of dated ring widths with which to cross-match it, a Master Chronology. To construct such a sequence we have to start with a sequence of widths whose dates are known and this means beginning with a sequence from an oak tree whose date of felling is known. In Figure A6 such a sequence is SHE-T, which came from a tree in Sherwood Forest which was blown down in a recent gale. After this other sequences which cross-match with it are added and gradually the sequence is ‘pushed back in time’ as far as the age of samples will allow. This process is illustrated in Figure A6. We have a master chronological sequence of widths for Nottinghamshire and East Midlands oak for each year from AD 882 to 1981. It is described in great detail in Laxton and Litton (1988), but the components it contains are shown here in the form of a bar diagram. As can be seen, it is well replicated in that for each year in this period there are several sample sequences having widths for that year. The master is the average of these. This master can now be used to date oak from this area and from the surrounding areas where the climate is very similar to that in the East Midlands. The Laboratory has also constructed a master for Kent (Laxton and Litton 1989). The method the Laboratory uses to construct a master sequence, such as the East Midlands and Kent, is completely objective and uses the Litton-Zainodin grouping procedure (Laxton et al 1988). Other laboratories and individuals have constructed masters for other areas and have made them available. As well as these masters, local (dated) site chronologies can be used to date other buildings from nearby. The Laboratory has hundreds of these site sequences from many parts of England and Wales covering many short periods.

7. Ring-Width Indices. Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form they take is explained in this paper and in the appendix of Laxton and Litton (1988) and is illustrated in the graphs in Figure A7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence of (a), the generally large early growth after 1810 is very apparent as is the smaller later growth from about 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings corresponding to good and poor growing seasons, respectively. The two corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.
Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

The bar diagram represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions (offsets) to each other at which they have maximum correlation as measured by the $t$-values. The $t$-value/offset matrix contains the maximum $t$-values below the diagonal and the offsets above it. Thus, the maximum $t$-value between C08 and C45 occurs at the offset of +20 rings and the $t$-value is then 5.6. The site sequence is composed of the average of the corresponding widths, as illustrated with one width.
Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.
**Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known**

Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences.

**Figure A7 (b): The Baillie-Pilcher indices of the above widths**

The growth trends have been removed completely.
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