THE OLD RECTORY,
YATTON KEYNELL, WILTSHIRE
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Matt Hurford, Martin Bridge and Cathy Tyers
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YATTON KEYNELL,
WILTSHIRE

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NGR: ST 8671 7639
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ISSN 1749-8775

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SUMMARY
Dendrochronological analysis was undertaken on 16 of the 17 samples taken from The Old Rectory, Yatton Keynell, Wiltshire. This resulted in the production of four site sequences, YKORSQ01–04, comprising four, two, three, and three samples respectively. YKORSQ01 and YKORSQ03 were both dated: YKORSQ01 as spanning the years AD 1404–92 and YKORSQ03 as spanning the years AD 1190–1293.
The results indicate that the dated timbers used in the construction of the hall roof are likely to represent a single programme of felling in the period AD 1300–25, whilst those used in the construction of the attic roof, also likely to represent a single programme of felling, were felled in the period AD 1505–30.

CONTRIBUTORS
Matt Hurford, Dr Martin Bridge, and Cathy Tyers

ACKNOWLEDGEMENTS
The laboratories would like to thank Mr Worlock for giving permission to undertake the work. Thanks are also due to Avis Lloyd for arranging access and for providing additional background material on the building and to Clive Carter of the Wiltshire Buildings Record for providing the drawings. Robert Howard, Nottingham Tree-ring Dating Laboratory, kindly produced the final versions of Figures 12–16. The Wiltshire Buildings Record project work was supported by the English Heritage Historic Environment Enabling Programme. The dendrochronological work was funded by English Heritage and coordinated by Peter Marshall from the Scientific Dating Team.

ARCHIVE LOCATION
Wiltshire Archaeological Service
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DATE OF INVESTIGATION
2009–10

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INTRODUCTION

In 2009 the Wiltshire Buildings Record successfully obtained support through the English Heritage Historic Environment Enabling Programme for their project ‘Wiltshire cruck buildings and other archaic roof types’. The detailed aims and objectives of the project are set out in the Project Design (Lloyd 2009). The overall aim is to establish a typological chronology of archaic roof types and hence elucidate the development of carpentry techniques in the county. This will then facilitate detailed comparison with other counties allowing Wiltshire to be placed in the regional context. Investigation of these late-medieval buildings (c AD 1200 – c AD 1550) will combine building survey, historical research, and dendrochronological analysis.

A series of buildings identified by the Wiltshire Buildings Record as having the potential to contribute to the aims and objectives of the project was assessed for dendrochronological suitability during 2009. In order to maximise the potential, these detailed dendrochronological assessments and the WBR’s assessments of the significance of the buildings within the project, informed the selection of the buildings subsequently subjected to detailed study.

A single final report produced by the Wiltshire Buildings Record (forthcoming a) will summarise the overall results from the project. However, each building included in the project will have an associated individual report produced by the WBR (forthcoming b), whilst the primary archive of the dendrochronological analysis is the English Heritage Research Department Report Series.

A brief introduction to dendrochronology can be found in the Appendix. Further details can be found in the guidelines published by English Heritage (1998), which are also available on the English Heritage website (http://www.english-heritage.org.uk/publications/dendrochronology-guidelines/).

The Old Rectory

The Old Rectory, a grade II listed property, lies in the centre of the village of Yatton Keynell, to the east of the Church of St Margaret of Antioch (ST 86717639; Figs 1 and 2). It is aligned on a north-west to south-east axis, but for ease of reference within this report the building has been described so that the front elevation facing The Street is described as the west elevation.

The focus of this investigation is on the surviving elements of the medieval open hall and the medieval extension to the south of the open hall (Fig 3). Details of the medieval remains are given below based on information provided in the Wiltshire Buildings Record report (forthcoming b).
The open hall, which is of base-cruck construction, is believed to date to the early fourteenth century on stylistic evidence. A single bay remains, incorporating two trusses, trusses A and B, although it is thought that this structure probably extended further north and originally comprised two bays. Truss A (Fig 4) has straight principals and quadrilateral arch braces with plain chamfers rising from a cambered tie beam, with the plate being clasped between the principals and lower arch braces. The collar is also cranked and there are two rows of tenoned purlins. The apex appears to be plain-butted, but is partially obscured. Whilst all other timbers are tenoned and pegged, the lateral timber above the collar is nailed and hence likely to be a later addition. Although only partially exposed, Truss B appears to be of largely similar form to Truss A.

The attic roof, immediately to the south of the open hall, comprises three partially visible cruck trusses, trusses C–E, which are on a slightly different alignment to trusses A and B. These are thought to represent a medieval extension to the open hall. The timbers of all three trusses are of similar scantling but there are some differences in detail. Truss D shows evidence for wind braces both to the north and south of this truss and also appears to have had an upper and lower collar. Truss E (Fig 5), probably originally an open truss, has a chamfered cranked collar with ogee-moulded arch braces.

SAMPLING

Sampling and analysis by tree-ring dating of the timbers associated with the remains of the roofs of the medieval open hall and attic were commissioned by English Heritage. It was hoped to provide independent dating evidence for the construction of the original medieval open hall and its subsequent medieval extension and hence inform the overall objectives of the Wiltshire Cruck Buildings and other archaic roof types project. The dendrochronological study also formed part of the English Heritage-funded training programme for the first author.

A total of ten timbers associated with the open hall and seven timbers associated with the attic roof were sampled by coring. Each sample was given the code YKO-R (for Yatton Keynell, Old Rectory) and numbered 01–17. The sampling encompassed as wide a range of elements as possible, whilst focussing on those timbers with the best dendrochronological potential. The timbers excluded from sampling in the open-hall roof appeared to be derived from fast-grown trees and were hence considered highly unlikely to provide samples with an adequate number of rings for reliable dendrochronological analysis. The limited access to trusses C, D, and E resulted in the sampling being restricted to the principals, the only exception being the collar of Truss E.

The location of samples was noted at the time of coring and marked on the drawings subsequently provided by the Wiltshire Buildings Record, these being reproduced here as Figures 6–11. Further details relating to the samples can be found in Table 1. In this table the timbers have been located and numbered following the scheme on the drawings provided, with the trusses being labelled A–E from the north to the south.
ANALYSIS AND RESULTS

Each of the 17 oak (Quercus spp.) cores obtained was prepared by sanding and polishing. It was seen at this point that one sample, YKO-R16, had too few rings for reliable dating purposes and so it was rejected from this programme of analysis. The annual growth rings of the remaining 16 samples were measured, the data of these measurements being given at the end of this report.

The ring sequences derived from these 16 samples were initially compared with each other by the Litton/Zainodin grouping procedure (see Appendix), allowing four groups of timbers to be formed. The samples of each group cross-match with each other as shown in Figures 12–15 and Tables 2–5. This analytical process was aided by the use of software written by Tyers (2004).

The individual series in each group were then combined at the indicated offsets to form site chronologies YKORSQ01–SQ04 (Figs 12–15). Intra-group cross-matching (Tables 2–5) indicated the possibility that some timbers may have been derived from the same-tree as suggested by t-values in excess of 10.0. However, to maintain consistency between all of the dendrochronological reports on individual buildings within this project, these potential same-tree series were not combined prior to incorporation into the site chronology, thus following the Nottingham Tree-Ring Dating Laboratory standard practice. All four site chronologies were compared to an extensive range of reference data for oak, this indicating repeated cross-matching for YKORSQ01 when the date of the first ring is AD 1404 and the date of its last ring is AD 1492 (Table 6) and for YKORSQ03 when the date of the first ring is AD 1190 and the date of its last ring is AD 1293 (Table 7). There was no conclusive cross-matching for either of the other two site chronologies, which therefore remain undated.

For consistency the sapwood estimate used in all of the dendrochronological reports on individual buildings within this project is the Nottingham Tree-Ring Dating Laboratory estimate of 15-40 (95% confidence) rings. This is used to calculate felling date ranges for samples with incomplete sapwood or felled-after dates for samples which are heartwood only.

The four site chronologies were compared with the remaining four ungrouped samples, but there was no further satisfactory cross-matching. Each of the four ungrouped samples was then compared with the reference chronologies, but again there was no satisfactory cross-matching and these 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>YKORSQ01</td>
<td>4</td>
<td>89</td>
<td>AD 1404–1492</td>
</tr>
<tr>
<td>YKORSQ02</td>
<td>2</td>
<td>95</td>
<td>undated</td>
</tr>
<tr>
<td>YKORSQ03</td>
<td>3</td>
<td>104</td>
<td>AD 1190–1293</td>
</tr>
<tr>
<td>YKORSQ04</td>
<td>3</td>
<td>61</td>
<td>undated</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>--</td>
<td>ungrouped and undated</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>--</td>
<td>not measured</td>
</tr>
</tbody>
</table>

**INTERPRETATION**

For consistency the sapwood estimate used in all of the dendrochronological reports on individual buildings within this project is the Nottingham Tree-Ring Dating Laboratory estimate of 15-40 (95% confidence) rings. This is used to calculate felling date ranges for samples with incomplete sapwood or felled-after dates for samples which are heartwood only.

The extant remains of the roof of the open hall of The Old Rectory are represented by three dated samples in site sequence YKORSQ03 (Fig 14). None of these samples has complete sapwood and it is thus not possible to calculate a precise felling date for the timbers represented. However, two samples did retain their heartwood/sapwood boundary ring, which varies in date by only two years, suggesting that these timbers are likely to represent a single felling programme. The average date for the heartwood/sapwood boundary ring is AD 1285, thus an estimated felling date in the range AD 1300–25 is obtained.

The remaining dated sample in site chronology YKORSQ03 has no trace of sapwood and thus it is not possible to calculate its likely felling date range. The date of its last measured ring is AD 1293. This produces an earliest likely felling date of AD 1309, indicating that it could have been felled during the same felling programme as the other two timbers in site sequence YKORSQ03. The level of cross-matching between the samples does not preclude them being a coherent group (Table 4).

The attic roof is represented by four dated samples in site sequence YKORSQ01 (Fig 12). None of these samples has complete sapwood and it is thus not possible to calculate a precise felling date for the timbers represented. Two of the samples, however, did retain their heartwood/sapwood boundary ring. This varies in date by only five years, again suggesting that these timbers are likely to represent a single felling phase. The average date for the heartwood/sapwood boundary is AD 1490. Hence estimated felling date in the range of AD 1505–30 is obtained.

The remaining two dated samples in site chronology YKORSQ01, YKO-R04 and YKO-R05, have no trace of sapwood and thus it is not possible to calculate their likely felling
date ranges. The date of their last measured rings indicates that they have earliest likely felling dates of AD 1498 and AD 1508 respectively. Thus they may also have been part of the same early sixteenth century felling programme identified above. This interpretation seems very likely when taking note of the high t-values obtained between pairs within this group (Table 2), which indicates the possibility that the pairs of samples represent the same tree or trees growing in close proximity.

The undated samples in site sequence YKORSQ02 are clearly likely to be coeval, with a heartwood/sapwood boundary date variation of only two years (Fig 13), as are those in YKORSQ04, the two heartwood/sapwood boundary dates again varying by only two years (Fig 14).

**DISCUSSION AND CONCLUSION**

Tree-ring analysis has indicated a felling date for three timbers associated with the open-hall roof in the early fourteenth century, thus supporting the date suggested previously based on stylistic evidence. Whilst this tree-ring evidence is based on only three timbers, these represent both extant trusses and also appear integral to the roof structure with no evidence of insertion or reuse.

The dated timbers from the attic roof are all four principals from trusses D and E which, in the absence of any evidence of insertion or reuse, suggests a construction date for this part of the extension to the south of the open hall in the early sixteenth century. Unfortunately the samples from truss C could not be dated, so the dating of this truss relies on its integral nature with the rest of the attic roof.

The high t-values have already been noted between the dated principals in the attic roof (see above; Table 4), the timbers from each truss representing halved trees. The level of cross-matching is also suggestive of the two truss C principals, forming YKORSQ02, potentially being derived from the same tree. In addition, the three samples in YKORSQ04, representing two plates and a tiebeam in the open-hall roof, appear likely to be derived from either the same tree or trees located in close proximity to each other, which further demonstrates the likelihood that the open-hall roof structure is of a single phase of construction. With respect to the potential same-tree pair from truss E, it is interesting to note the date of the heartwood/sapwood boundary of the east principal is earlier in date than the outermost measured heartwood ring of the west principal of truss E. This potentially serves to demonstrate the variation in heartwood formation throughout the outermost rings, which is usual in oak trees.

The inability to date YKORSQ02, which represents the truss C principals in the attic, does not necessarily suggest that they are of a different date to trusses D and E, but may simply mean that they are derived from a tree that has responded to different, potentially highly localised growth conditions. The latter half of this sequence is clearly dominated by a series of bands of narrow rings followed by a period of recovery, indicating that this tree suffered a number of growth-retardation events, which will have masked the more
general climatic signal required for successful dating purposes. Site chronology YKORSQ04 also remains undated. Again, this may simply be due to the timbers represented being derived from a tree or trees that have responded to different growth conditions. In this instance the sequence is very short and includes a sudden growth retardation event towards the middle. Both of these factors will significantly reduce the chances of successful dating.

It is apparent from Tables 6 and 7 that the timbers from both the open hall and attic are most likely to be from relatively local woodlands. Site chronology YKORSQ03 produces the highest t-values, and thus shows the greatest degree of similarity, with reference chronologies from Wiltshire and the surrounding region. Site chronology YKORSQ01 produces high t-values with a more diverse set of reference chronologies. Nevertheless, the strongest overall cross-matching is with reference chronologies from Wiltshire and the surrounding region.

Two of the four ungrouped and undated samples, YKO-R02 and YKO-R17, show clear disturbances to their growth patterns, which again would reduce the chances of successful cross-matching and dating. The chances of dating individual ring sequences are always lower than that of a well-replicated site sequence in which the common climatic signal is enhanced at the expense of the background ‘noise’ resulting from the local growth conditions of individual trees.

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Wiltshire Buildings Record forthcoming b *The Old Rectory, Yatton Keynell*, WBR report

### TABLES

**Table 1: Details of tree-ring samples from The Old Rectory, Yatton Keynell, Wiltshire**

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Sample location</th>
<th>Total rings</th>
<th>Sapwood rings</th>
<th>Average Ring Width</th>
<th>Cross-section dimensions</th>
<th>First measured ring date (AD)</th>
<th>Last heartwood ring date (AD)</th>
<th>Last measured ring date (AD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>YKO-R01</td>
<td>Truss E west principal</td>
<td>59</td>
<td>--</td>
<td>2.55</td>
<td>200+x280</td>
<td>1431</td>
<td>----</td>
<td>1489</td>
</tr>
<tr>
<td>YKO-R02</td>
<td>Truss E collar</td>
<td>50</td>
<td>h/s</td>
<td>1.83</td>
<td>180+x250</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>YKO-R03</td>
<td>Truss E east principal</td>
<td>53</td>
<td>h/s</td>
<td>2.56</td>
<td>140+x280</td>
<td>1435</td>
<td>1487</td>
<td>1487</td>
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<tr>
<td>YKO-R04</td>
<td>Truss D east principal</td>
<td>79</td>
<td>--</td>
<td>3.32</td>
<td>170x280</td>
<td>1404</td>
<td>----</td>
<td>1482</td>
</tr>
<tr>
<td>YKO-R05</td>
<td>Truss D west principal</td>
<td>77</td>
<td>h/s</td>
<td>2.49</td>
<td>170x300</td>
<td>1416</td>
<td>1492</td>
<td>1492</td>
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<tr>
<td>YKO-R06</td>
<td>Truss C west principal</td>
<td>95</td>
<td>19</td>
<td>2.09</td>
<td>170x280</td>
<td>----</td>
<td>----</td>
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<tr>
<td>YKO-R07</td>
<td>Truss C east principal</td>
<td>81</td>
<td>16c</td>
<td>2.19</td>
<td>150x300</td>
<td>----</td>
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<tr>
<td>YKO-R08</td>
<td>Truss C tiebeam</td>
<td>93</td>
<td>h/s</td>
<td>1.15</td>
<td>150x290</td>
<td>1194</td>
<td>1286</td>
<td>1286</td>
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<tr>
<td>YKO-R09</td>
<td>Truss B east arch brace to collar</td>
<td>80</td>
<td>5c</td>
<td>1.18</td>
<td>100x220</td>
<td>----</td>
<td>----</td>
<td>----</td>
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<tr>
<td>YKO-R10</td>
<td>Truss B east plate</td>
<td>53</td>
<td>--</td>
<td>3.50</td>
<td>220x220</td>
<td>----</td>
<td>----</td>
<td>----</td>
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<tr>
<td>YKO-R11</td>
<td>Truss A east plate</td>
<td>59</td>
<td>h/sc</td>
<td>2.94</td>
<td>190x210</td>
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<tr>
<td>YKO-R12</td>
<td>Truss A tiebeam</td>
<td>55</td>
<td>h/s</td>
<td>2.52</td>
<td>220x290</td>
<td>----</td>
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<tr>
<td>YKO-R13</td>
<td>Truss A west principal</td>
<td>104</td>
<td>--</td>
<td>1.40</td>
<td>140x180</td>
<td>1190</td>
<td>----</td>
<td>1293</td>
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<tr>
<td>YKO-R14</td>
<td>Truss A east arch brace to collar</td>
<td>65</td>
<td>h/s</td>
<td>1.27</td>
<td>100x190</td>
<td>1220</td>
<td>1284</td>
<td>1284</td>
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<tr>
<td>YKO-R15</td>
<td>Truss A west plate</td>
<td>68</td>
<td>h/s</td>
<td>1.25</td>
<td>180x210</td>
<td>----</td>
<td>----</td>
<td>----</td>
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<tr>
<td>YKO-R16</td>
<td>Truss A collar</td>
<td>nm</td>
<td>--</td>
<td>--</td>
<td>170x180</td>
<td>----</td>
<td>----</td>
<td>----</td>
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<tr>
<td>YKO-R17</td>
<td>Truss B east principal</td>
<td>76</td>
<td>--</td>
<td>1.88</td>
<td>160x180</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>

*nm = not measured
*h/s = the heartwood/sapwood ring is the last ring on the sample
*c = complete sapwood was present on the timber but part was lost from the sample during coring
*+ = the timber was embedded within the wall thus the complete dimension could not be measured
Table 2: Cross-matching between the samples in site sequence YKORSQ01; - indicates that the t-value is less than 3.0

<table>
<thead>
<tr>
<th></th>
<th>yko-r03</th>
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<th>yko-r05</th>
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<tbody>
<tr>
<td>yko-r01</td>
<td>9.72</td>
<td>4.37</td>
<td>3.31</td>
</tr>
<tr>
<td>yko-r03</td>
<td></td>
<td>3.44</td>
<td>-</td>
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<tr>
<td>yko-r04</td>
<td></td>
<td></td>
<td>10.28</td>
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Table 3: Cross-matching between the samples in site sequence YKORSQ02

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<th>yko-r07</th>
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<tbody>
<tr>
<td>yko-r06</td>
<td>12.01</td>
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Table 4: Cross-matching between the samples in site sequence YKORSQ03

<table>
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<tr>
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<th>yko-r13</th>
<th>yko-r14</th>
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</thead>
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<tr>
<td>yko-r08</td>
<td>4.45</td>
<td>4.98</td>
</tr>
<tr>
<td>yko-r13</td>
<td></td>
<td>5.35</td>
</tr>
</tbody>
</table>

Table 5: Cross-matching between the samples in site sequence YKORSQ04

<table>
<thead>
<tr>
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<th>yko-r11</th>
<th>yko-r12</th>
</tr>
</thead>
<tbody>
<tr>
<td>yko-r10</td>
<td>14.75</td>
<td>9.73</td>
</tr>
<tr>
<td>yko-r11</td>
<td></td>
<td>9.02</td>
</tr>
</tbody>
</table>
Table 6: Results of the cross-matching of site sequence YKORSQ01 and relevant reference chronologies when the first-ring date is AD 1404 and the last-ring date is AD 1492

<table>
<thead>
<tr>
<th>Reference chronology</th>
<th>t-value</th>
<th>Span of chronology</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fulham Palace, Hammersmith, London</td>
<td>7.3</td>
<td>AD 1356–1494</td>
<td>(Bridge and Miles 2004)</td>
</tr>
<tr>
<td>Acton Court, Gloucestershire</td>
<td>7.0</td>
<td>AD 1328–1575</td>
<td>(Haddon-Reece et al 1990)</td>
</tr>
<tr>
<td>Dauntsey House, Dauntsey, Wiltshire</td>
<td>6.8</td>
<td>AD 1393–1580</td>
<td>(Hurford et al forthcoming a)</td>
</tr>
<tr>
<td>St Johns Hospital, Lichfield, Staffordshire</td>
<td>6.6</td>
<td>AD 1356–1494</td>
<td>(Worthington and Miles 2002)</td>
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<tr>
<td>West Molesey, Elmbridge, Surrey</td>
<td>6.6</td>
<td>AD 1382–1502</td>
<td>(Arnold and Howard 2006)</td>
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<tr>
<td>Daubeneys, Colerne, Wiltshire</td>
<td>6.4</td>
<td>AD 1347–1497</td>
<td>(Hurford et al forthcoming b)</td>
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<tr>
<td>Sherbourne Abbey Church, Dorset</td>
<td>6.4</td>
<td>AD 1339–1474</td>
<td>(Bridge 1993)</td>
</tr>
<tr>
<td>Frocester barn, Gloucestershire</td>
<td>6.2</td>
<td>AD 1380–1513</td>
<td>(Fletcher et al 1985)</td>
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Table 7: Results of the cross-matching of site sequence YKORSQ03 and relevant reference chronologies when the first-ring date is AD 1190 and the last-ring date is AD 1293

<table>
<thead>
<tr>
<th>Reference chronology</th>
<th>t-value</th>
<th>Span of chronology</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exeter Cathedral, Exeter, Devon</td>
<td>8.7</td>
<td>AD 1132–1315</td>
<td>(Howard et al 2001)</td>
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<tr>
<td>Polesworth Abbey Gatehouse, Warwickshire</td>
<td>8.4</td>
<td>AD 1095–1342</td>
<td>(Arnold and Howard 2007)</td>
</tr>
<tr>
<td>Fiddleford Manor, Sturminster Newton, Dorset</td>
<td>8.2</td>
<td>AD 1167–1315</td>
<td>(Bridge 2003)</td>
</tr>
<tr>
<td>Tithe Barn, Englishcombe, near Bath</td>
<td>8.1</td>
<td>AD 1157–1304</td>
<td>(Groves and Hillam 1994)</td>
</tr>
<tr>
<td>Bremhill Court, Bremhill, Wiltshire</td>
<td>8.0</td>
<td>AD 1111–1323</td>
<td>(Hurford et al 2010)</td>
</tr>
<tr>
<td>Dauntsey House, Dauntsey, Wiltshire</td>
<td>7.6</td>
<td>AD 1122–1355</td>
<td>(Hurford et al forthcoming a)</td>
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<tr>
<td>Great Coxwell Barn, Oxfordshire</td>
<td>7.4</td>
<td>AD 1043–1267</td>
<td>(Siebenlist-Kerner et al 1978)</td>
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<tr>
<td>Wick Farm Cottage, Heddonwick Wick, Wiltshire</td>
<td>7.1</td>
<td>AD 1158–1335</td>
<td>(Hurford et al forthcoming c)</td>
</tr>
</tbody>
</table>
Figure 1: Map to show the location of Yatton Keynell, Wiltshire (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 The Old Rectory within the village of Yatton Keynell (based on the Ordnance Survey map with permission of the Controller of Her Majesty’s Stationery Office, © Crown Copyright)
Figure 3: General view of west (south-west) elevation of The Old Rectory showing locations of the open hall and attic roof

Figure 4: South face of open hall truss A
Figure 5: North face of attic truss E

Figure 6: Basic plan of the roof showing the truss locations in the open hall and attic
Figure 7: South face of truss A showing the sample locations

Figure 8: South face of truss B showing the sample locations
Figure 9: North face of truss C showing the sample locations

Figure 10: North face of truss D showing the sample locations
Figure 11: North face of truss E showing the sample locations

Figure 12: Bar diagram of the samples in site chronology YKORSQ01

- White bars = heartwood rings
- h/s = the last ring of the sample is at the heartwood/sapwood boundary

Figure 13: Bar diagram of the samples in site chronology YKORSQ02

- White bars = heartwood rings
- Filled bars = sapwood rings
- c = complete sapwood exists on the timber but part of the sapwood on the sample has been lost during coring
White bars  = heartwood rings
h/s = the last ring of the sample is at the heartwood/sapwood boundary

d = incomplete sapwood does not exist on the timber

Figure 14: Bar diagram of the samples in site chronology YKORSQ03

Figure 15: Bar diagram of the samples in site chronology YKORSQ04
 DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

<table>
<thead>
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<th>Sample Code</th>
<th>Measurements</th>
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<tr>
<td>YKO-R01A 59</td>
<td>324 335 154 210 219 322 368 314 293 309 408 262 292 301 256 260 285 248 257 212</td>
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<tr>
<td>YKO-R01B 59</td>
<td>320 335 152 209 217 329 366 309 301 302 403 262 289 302 253 266 284 249 258 208</td>
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<tr>
<td>YKO-R02A 50</td>
<td>135 224 382 258 221 103 102 51 55 85 118 129 235 230 246 235 299 257 86 94 104 95 102 103 163 149 196 171 279 238 270 371 78 80 108 83 107 128 188</td>
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<tr>
<td>YKO-R02B 50</td>
<td>141 221 377 263 213 106 103 45 59 86 122 154 121 217 246 258 229 252 273 84 109 83 97 93 158 156 197 175 271 236 263 372 80 77 111 80 110 129 188</td>
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<tr>
<td>YKO-R03A 53</td>
<td>424 510 473 513 437 406 453 345 417 424 316 311 356 400 461 276 341 290 212 326 195 210 229 208 155 150 128 123 100 83 98 226 302 267 227 237 224 173 145 139</td>
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<tr>
<td>YKO-R03B 53</td>
<td>418 510 469 551 440 415 469 335 419 423 327 309 352 406 422 283 345 266 215 316 200 194 204 191 168 153 133 117 101 78 104 220 315 279 226 237 219 179 145 141 176 154 104 117 197 223 166 202 209 208 182 167 212</td>
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<tr>
<td>YKO-R04B 79</td>
<td>244 258 494 394 481 511 420 495 577 413 366 381 366 443 442 280 356 410 331 327 353 270 371 430 467 468 420 393 507 225 118 133 134 151 109 103 188 228 148 191 205 211 213 206 340 406 426 423 328 270 376 406 356 388 403 365 426 312 269 381 236 298 339 372 330 347 362 301 301 329 368 410 400 258 293 306 379 333 246</td>
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<tr>
<td>YKO-R05A 77</td>
<td>331 431 434 265 274 294 210 296 330 232 274 333 303 296 235 246 236 127 84 78 68 91 124 118 186 230 152 197 212 211 160 168 221 323 341 347 342 299 362 319 342 391 390 373 401 321 300 396 284 392 355 374 304 323 245 272 293 296 331 284 245 198 204 231 287 256 262 235 159 71 62 67 51 70 92 107 89</td>
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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 flour-grade-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 (ie 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...
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.
References


Laxton, R R, and Litton, C D, 1988 An *East Midlands Master Chronology and its use for dating vernacular buildings*, University of Nottingham, Department of Archaeology Publication, Monograph Series III


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