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HARTLEBURY CASTLE, NEAR STOURPORT-ON-SEVERN, WORCESTERSHIRE
DENDROCHRONOLOGICAL ANALYSIS OF OAK TIMBERS

SCIENTIFIC DATING REPORT

Ian Tyers

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SUMMARY

A tree-ring dating programme was commissioned on timbers from Hartlebury Castle. The results identified that timbers in four areas of roof and a bell cupola were datable by tree-ring dating techniques, with these areas using timbers felled during the fifteenth, seventeenth, and eighteenth centuries. This dating programme was commissioned on this Grade I historic residence of the Bishops of Worcester to support casework during its sale and consideration for entry on the Buildings at Risk register. This report archives the dendrochronological results.

CONTRIBUTORS

Ian Tyers

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ARCHIVE LOCATION

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CONTENTS

INTRODUCTION

This document is a technical archive report on the tree-ring analysis of oak timbers from Hartlebury Castle, Worcestershire. It is beyond the dendrochronological brief to describe the building in detail or to undertake the production of detailed drawings. Elements of this report may be combined with detailed descriptions, drawings, and other technical reports at some point in the future to form either a comprehensive publication or an archive deposition on the building.

Hartlebury Castle stands to the western edge of the village of Hartlebury, *c* 5km south of Kidderminster, and *c* 2.5km east of Stourport-on-Severn (NGR SO 8360 7125) within the county of Worcestershire (Fig 1). This Grade-I listed building has been a principal residence of the Bishops of Worcester since at least the later thirteenth century. It comprises a large C-shaped building, standing in parkland with formal gardens to the east, and a large moat to the west. At the time of sampling, the northern wing was occupied as the county museum for Worcestershire. The central and southern wings stood empty, with most of the contents in the process of being moved to a residence in the cathedral precincts in Worcester. The building contains extensive remains of the medieval hall and service areas, and a series of roofs reflecting programmes of aggrandisement during the seventeenth and eighteenth centuries. Apart from the magnificent Great Hall, the Castle also contains Bishop Hurd's important collection of books and its purpose-built library, and the architecturally important mid-eighteenth century chapel decorated with fan vaulting in plasterwork.

METHODOLOGY

Tree-ring dating employs the patterns of tree-growth to determine the calendar dates for the period during which the sampled trees were alive. The amount of wood laid down in any one year by most trees is determined by the climate and other environmental factors. Trees over relatively wide geographical areas can exhibit similar patterns of growth, and this enables dendrochronologists to assign dates to some samples by matching the growth pattern with other ring-sequences that have already been linked together to form reference chronologies.

Hartlebury was visited in March 2008. An assessment of the dendrochronological potential of timbers throughout the castle had been requested by Nicholas Molyneux. This assessment aimed to identify whether oak timbers with sufficient numbers of rings for analysis existed in any part of the complex. This assessment concluded that the timbers in four separate areas of roof, along with the bell cupola base frame, all contained suitable material. The area of roof over the saloon appeared to contain a variety of timbers, perhaps from several different periods of construction, whilst on a subsequent visit the Hurd library roof timbers were assessed as unsuitable for sampling and analysis.

The sampling took place during May 2008. The selected timbers were sampled using a 15mm-diameter corer attached to an electric drill. The cores were taken as closely as possible along the radius of the timbers, so that the maximum number of rings could be obtained for subsequent analysis. The ring sequences in the cores were revealed by sanding.

This preparation revealed the width of each successive annual tree ring. Each prepared sample could then be accurately assessed for the number of rings it contained, and at this stage it was also possible to determine whether the sequence of ring widths within it could be reliably resolved. Dendrochronological samples need to be free of aberrant anatomical features, such as those caused by physical damage to the tree, which may prevent or significantly reduce the chances of successful dating.

Standard dendrochronological analysis methods (see eg English Heritage 1998) were applied to each suitable sample. The complete sequence of the annual growth rings in the suitable samples was measured to an accuracy of 0.01mm using a micro-computer based travelling stage. The sequences of ring widths were then plotted onto semi-log graph paper to enable visual comparisons to be made between sequences. In addition, cross-correlation algorithms (eg Baillie and Pilcher 1973) were employed to search for positions where the ring sequences were highly correlated (Tyers 2004). Highly correlated positions were checked using the graphs and, if any of these were satisfactory, new composite sequences were constructed from the synchronised sequences. Any *t*-values reported below were derived from the original CROS algorithm (Baillie and Pilcher 1973). A *t*-value of 3.5 or over is usually indicative of a good match, although this is with the proviso that high *t*-values at the same relative or absolute position need to have been obtained from a range of independent sequences, and that these positions were supported by satisfactory visual matching.

Not every tree can be correlated by the statistical tools or the visual examination of the graphs. There are thought to be a number of reasons for this: genetic variations; site-specific issues (for example, a tree growing in a stream bed will be less responsive to rainfall); or some traumatic experience in the tree's lifetime, such as injury by pollarding, defoliation events by caterpillars, or similar. These could each produce a sequence dominated by a non-climatic signal. Experimental work with modern trees shows that 5–20% of all oak trees cannot be reliably cross-matched, even when enough rings are obtained.

Converting the date obtained for a tree-ring sequence into a useful date requires a record of the nature of the outermost rings of the sample. If bark or bark-edge survives, a felling date precise to the year or season can be obtained. If no sapwood survives, the date obtained from the sample gives a *terminus post quem* for its use. If some sapwood survives, an estimate for the number of missing rings can be applied to the end-date of the heartwood. This estimate is quite broad and varies by region. This report uses a

minimum of 10 rings and a maximum of 46 rings as a sapwood estimate (see eg English Heritage 1998, 10–11).

Where bark-edge or bark survives, the season of felling can be determined by examining the completeness or otherwise of the terminal ring lying directly under the bark. Complete material can be divided into three major categories:

- 'early spring', where only the initial cells of the new growth have begun – this is equivalent to a period in March/April, when the oaks begin leaf-bud formation;
- 'later spring/summer' where the early wood is complete but the late wood is evidently incomplete, which is equivalent to May-through-September of a normal year, and
- 'winter' where the latewood is evidently complete and this is roughly equivalent to September-to-March (of the following year) since the tree is dormant throughout this period and there is no additional growth put on the trunk.

These categories can overlap as, for example, not all oaks simultaneously initiate leaf-bud formation. It should also be noted that slow growing or compressed material cannot always be safely categorised.

Timber technology studies demonstrate that many of the tool marks recorded on ancient timbers can only have been done on green timber. There is little evidence for long-term storage of timber or of widespread use of seasoned, rather than green, timber in the medieval period (see eg English Heritage 1998, 11–12).

Reused timbers can only provide tree-ring dates for the original usage date, not their reuse. Identifying reused timbers requires careful timber recording which notes the presence of features which are not functional in the structure. It is always possible that some timbers exhibit no evidence of earlier usage, and are thus 'hidden reused' timbers. The dendrochronological impact of this problem is particularly acute where only single timbers have been dated from a structure.

The analysis may highlight potential same-tree identifications if two or more tree-ring sequences are obtained that are exceptionally highly correlated. Such pairs, or sometimes more, are then used as a same-tree group and each can be given the interpreted date of the most complete of the samples. They are most useful where several timbers date but only one has any sapwood, or where same-tree identifications yield linkages between different areas.

RESULTS

In May 2008 45 timbers of five separate areas of the building were cored. These cores were labelled 1–45 inclusive. Sampling proceeded from the chapel in the south-east through to the kitchen area in the north. Eight timbers were sampled in the chapel roofs,

17 from a variety of types of material in the saloon roof, six from the bell cupola base frame, eight from the great hall roof, and six from the kitchen (Figures 2–8). Each sample was assessed for the wood type, the number of rings it contained, and whether the sequence of ring widths could be reliably resolved. This assessment confirmed that all the sampled timbers were oak (*Quercus* spp.) and that 41 were suitable for dendrochronological analysis. The four exceptions were sample 8 from a roof to the north of the chapel area, and samples 40–2 inclusive from the kitchen roof, all of which had either too few rings for analysis or had fragmented badly during sampling. The readily accessible areas of the building have had an extensive programme of defrassing (physical removal of sapwood, usually with a hatchet) in the relatively recent past, hence survival of sapwood was poor and bark-edge survived only rarely. The details of these samples are provided in Table 1.

The samples were prepared for analysis and measured, and the resultant ring sequences were then compared with each other. All eight of the samples from the great hall roof were found to cross-match each other (Table 2), the three suitable samples from the kitchen roof cross-matched (Table 3), all seventeen samples from the saloon roof cross-matched (Table 4), the seven suitable samples from the chapel roof cross-matched (Table 5), and all six of the samples from the bell cupola cross matched (Table 6). Each cross-matched group was then combined into a single composite data set. These were then compared with each other, the composite series from the first four areas were found to form an internally consistent group (Table 7), with a tentative very short overlap link to the fifth, later, bell cupola sequence. These site composites are of rather different growth characteristics, lengths, and dates, so each of the five composite sequences was therefore compared separately with medieval and later tree-ring data from throughout England and Wales. Each of the composite sequences was found to cross-match, particularly against data from sites in the West Midlands and/or South-West regions (Tables 8–11). This cross-matching provided consistent calendar dates for each of the sequences, and confirmed the correlations between them shown in Table 7. A summary of the results for the component samples of these chronologies are provided in Table 1 and Figure 9. The measurement data for all the measured samples are listed in Appendix 1.

DISCUSSION

The dated samples are derived from five different parts of Hartlebury, each of a different date, or in one case of at least two different dates. These parts are discussed in their date order below.

Great Hall roof

The Great Hall roof comprises six trusses (numbered T1 to T6 from the north, following Molyneux in prep, and the medieval numbers; Fig 3). The end trusses are set against the north and south walls of the hall, which is *c* 8m east-west by *c* 19m north-south. Each truss rises from moulded stone corbels high up the walls of the hall. There are no

tiebeams; instead, the trusses are more akin to jointed crucks, with the short wall posts jointed to the principal rafters. Arch braces support a collar, V-struts rise from the centre of the collar, the purlins and principal rafters are decorated with roll mouldings, and the central common rafter of each bay forms an intermediate truss. The roof now has a ceiling just above collar level, possibly inserted to give access to the bell cupola. Here there is evidence for wind bracing formerly rising to the main trusses. There is some disturbance in one bay, and a change of ridge configuration suggestive of the presence of a smoke louvre.

The eight samples from this area comprised three principal rafters, three purlins, and two of the V-struts. All were sampled in the narrow access corridor formed by the high ceiling. All the samples were suitable for analysis and all were found to cross-match. The composite sequence was found to date and thus there are tree-ring dates for all eight of these structural elements. The 194-year composite sequence was found to strongly match composite sequences obtained from the surrounding regions (Table 8) and it is most likely that these timbers were derived from the general vicinity of Hartlebury. It should be noted that this material comprised oaks of a variety of growth rates and ages, perhaps indicating the material was derived from a variety of locations, a suggestion supported by the poorer inter-correlation values of this material compared with the other sample groups from the building. The cross-dating indicated an early-fifteenth century date for all the datable timbers.

The tree-ring analysis dates the rings present in the cores. The correct interpretation of those dates relies upon the characteristics of the final rings in them. Bark-edge survived on none of these timbers, but significant amounts of sapwood were recovered from one, the heartwood/sapwood boundary was present on a further six, and the remaining sample entirely consisted of heartwood. Making allowances for minimum and maximum likely amounts of missing sapwood provides individual felling date ranges or *terminus post quem* dates for each of the datable timbers. Figure 9 and Table 1 includes the interpreted felling date ranges or *terminus post quem* dates for each of the datable samples.

The calculation of the common felling period for each sampled timber from this roof suggests a construction date between AD 1428 and *c* AD 1447. The mathematical combination of estimated sapwood distributions is statistically complex, and to achieve a tighter interpretation would require reliable sapwood data for the area, period, and the specific character of these oaks. Such data are not presently available. Until that point, the use of robust combinatorial methods or alternative statistical approaches might sacrifice a broad and indicative date for a narrower one of potentially spurious precision. It is clear, however, that this roof uses timbers felled in the second quarter of the fifteenth century.

Sadly, this result excludes any possibility that the existing roof structure was built using 22 great oak trees documented to have been brought to the castle in AD 1395/6 from Welland, which is *c* 30km south of Hartlebury (Molyneux pers comm). This phase is therefore due to the period of Bishops Poulton, Brunce, Bourchier, or Carpenter, and not

Bishop Tideman as has previously been suggested. It is possible that documentary research may identify a likely reference to its construction somewhere within the relatively narrow date range identified by the tree-ring analysis.

Kitchen roof

Running to the north and off to the west of the Great Hall is a five-bay building that may be the medieval kitchen; or it may be a brewhouse, since a five-bay brewhouse was recorded in a later survey. Some of the wall posts and tiebeams of the southern trusses are visible in the present visitor cafeteria. It is accessible from above via a rather difficult route through a later roof built over it. This roof is considered to be the structure in the poorest condition of all those in the complex. The two visible roof trusses at the southern end have V-struts and two rows of purlins (Fig 4). The timbers in this roof mostly comprised halved young oaks. The six samples were obtained from a principal rafter, two purlins, the collar, and two V-struts from the southernmost truss, the only one safely accessible. Only three of these samples were suitable for analysis. Each yielded a short but usable sequence and all three were cross-matched and dated. The 80-year composite sequence was found to strongly match the material from the saloon and chapel roofs at Hartlebury (Table 7), as well as other composite sequences obtained from the vicinity (Table 9). It is thus most likely that these timbers were derived from the immediate vicinity of Hartlebury. This material comprised faster-growing and shorter-lived oaks than many of those used elsewhere at Hartlebury. The cross-dating indicated a later fifteenth-century date for the datable timbers from this truss.

Bark-edge survived on one of these timbers, significant amounts of sapwood on another, and only heartwood on the third. No allowance needs to be made for missing sapwood from the complete sample, allowances for minimum and maximum likely amounts of missing sapwood provide a individual felling date range and a *terminus post quem* date for the other two datable timbers. Figure 9 and Table 1 include the interpreted felling date, felling date range, and *terminus post quem* date for each of the datable samples.

The interpretation of this material is straightforward. The sample complete to bark edge retains a complete ring for AD 1468, and the onset of growth for AD 1469, so this sample (a V-strut) were felled in the early spring of AD 1469. The calculated felling date range, and *terminus post quem* date for the remaining two samples indicated this material was either precisely or broadly contemporaneous.

The kitchen, or brewhouse, roof was therefore built with timber felled in AD 1469, which is 20 to 40 years later than the present Great Hall roof. This structure can therefore be associated with the extensively documented building works of Bishop Carpenter, who was the bishop until AD 1476.

Saloon roof

The area over the saloon is roofed with five trusses, each with massive principal rafter and queen strut trusses, with relatively slight vertical struts rising to large collars (Fig 5). The intended effect was to bring the roof line of the Great Hall and Saloon into alignment making it appear to be a continuous structure. The northernmost truss (numbered T5 after Molyneux in prep) is against the formerly external wall of the Great Hall. The southernmost truss (numbered T1 after Molyneux in prep) is against the presumed seventeenth-century brick wall of the staircase block, and is closed, with widely spaced stud work. This roof appears to contain a mixture of timber; there are some certainly reused elements. These are usually, though not exclusively, in the queen struts, but in addition the beautifully finished and clean timbers of the principal rafters, derived from quartered oaks, are jointed into very roughly hewn whole-oak tiebeams. The mortises in the latter appear too large, and have too many peg holes, for the principal rafters that are currently in them.

An extensive programme of sampling was undertaken in this roof in an attempt to understand this structure. In total, 17 samples were obtained: five principal rafters, all five tiebeams, two purlins, a collar, a queen strut, two common rafters, and the western wall plate. All 17 were suitable for analysis and all 17 were cross-matched and dated. The 270-year composite sequence was found to strongly match sequences from the chapel roof (Table 7) as well as other composite sequences obtained from the vicinity (Table 10). It is thus most likely that these timbers were derived from the immediate vicinity of Hartlebury. The material comprised a mixture of fast- and slow-growing and short- and long-lived oaks. This cross-dating indicated an early seventeenth-century date for most the datable timbers from this area, although two were evidently of mid-fifteenth-century date.

Bark-edge survived on none of these timbers, sapwood survived on five, the heartwood/sapwood boundaries were present on another seven, and the remaining five comprised only heartwood. Making allowances for minimum and maximum likely amounts of missing sapwood provides individual felling date ranges or *terminus post quem* dates for each of the datable timbers. Figure 9 and Table 1 include the interpreted felling date ranges and *terminus post quem* dates for each of the datable samples.

The analytical results from this area clearly indicate the presence of two different groups of material. The discussion that follows segregates the material firstly on the basis of the analytical results and secondly on their differing structural sources.

Early timbers

Samples 17 (a timber reused as a queen strut) and 20 (a common rafter) retain heartwood/sapwood boundaries at AD 1408 and AD 1420 respectively. The calculation of the common felling period for these, if we assume they were derived from a single structure, suggests a felling date between *c* AD 1430 and *c* AD 1454. The mathematical

combination of estimated sapwood distributions is statistically complex, and to achieve a tighter interpretation would require reliable sapwood data for the area, period, and the specific character of these oaks. Such data are not presently available. Until that point, the use of robust combinatorial methods or alternative statistical approaches might sacrifice a broad and indicative date for a narrower one of potentially spurious precision. It is clear, however, that the saloon roof utilises a handful of timbers felled in the second quarter of the fifteenth century. If this material was derived from Hartlebury, which is not certain, these timbers could have been salvaged from modifications to the Great Hall roof, or some other fifteenth-century structure that is no longer extant.

Later timbers

The remaining 15 samples include ten that retain some sapwood or the heartwood/sapwood boundaries. The calculation of the common felling period for these, if we assume they were derived from a single structure, suggests a felling date between AD 1608 and *c* AD 1629. The mathematical combination of estimated sapwood distributions is statistically complex, and to achieve a tighter interpretation would require reliable sapwood data for the area, period, and the specific character of these oaks. Such data are not presently available. Until that point the use of robust combinatorial methods, or alternative statistical approaches might sacrifice a broad and indicative date for a narrower one of potentially spurious precision. It is clear, however, that this roof utilises a lot of timbers felled in the first quarter of the seventeenth century. This material can be further divided by its location within the structure.

Five tiebeams and a wall plate

Samples 11, 13, 16, 21, and 23 comprise the five saloon roof tiebeams in the order T5–T1. Sample 39 was obtained from the western wall plate between T3 and T4. These timbers are fully jointed elements of the roof, and each has the same relatively rough-hewn finish. The tiebeams are, at present, surrounded by modern insulating glass fibre and are difficult to examine in detail. The identification of the presence of sapwood and, with their awkward proximity to the end walls, even obtaining the correct coring angle was unusually difficult with the T1 and T5 tiebeams, as well as with the wall plate. These six timbers include four of the five from the saloon area that are exclusively heartwood, and they have heartwood end-dates of AD 1486, AD 1487, AD 1545, and AD 1584. The other two retained heartwood/sapwood boundaries, and the boundary rings were dated to AD 1590 and AD 1593. The calculation of the common felling period for these suggests a felling date between *c* AD 1603 and *c* AD 1636, which is certainly appropriate for the tiebeams from T2 and T3 and almost inevitably for the T4 tiebeam, since this ends in heartwood at AD 1584.

A viable conclusion is that despite the widely differing end dates, which may be entirely due to access difficulties resulting in sub-optimal sampling, these elements do not appear to be any different in date to the other primary parts of the saloon roof.

An alternative hypothesis, that these results could allow for, is that the T1 and T5 tiebeams and the western wall plate are reused, the two tiebeams from no earlier than AD 1497, the wall plate from no earlier than AD 1555. However, since there were no differences noted at the time of sampling between these and the central three tiebeams, this is probably not a viable suggestion, particularly as the wall plate was pegged to two of these tiebeams. One anomaly is that the western wall plate retains chamfers and stops, but these were not observed on the tiebeams, although access was restricted to this material. If the glass fibre insulating material can be safely moved, it would be worthwhile carefully examining this framework for both carpenters' numbers and decorative mouldings. It is not unknown for decorative features to be hacked off the bottoms of such timbers in order to provide a level platform for a plaster ceiling.

Five principal rafters, two purlins, a collar, and a common rafter

The remaining nine samples comprise elements of the above-tiebeam saloon roof structure. These include one entirely heartwood sample, ending at AD 1531, three samples ending at heartwood/sapwood boundaries dating to AD 1588, AD 1589, and AD 1597, and the five samples with some sapwood. The latter have their heartwood/sapwood boundaries dating to AD 1583, AD 1586, AD 1592, AD 1595, and AD 1598. Two of these retain sufficient sapwood to constrain their earliest possible felling dates to AD 1606 and AD 1608. The calculation of the common felling period for these suggests a felling date between AD 1608 and *c* AD 1629. These elements appear to be the same age as the tiebeams to which they are connected, and their different surface patina and their apparently ill-fitting joints thus do not appear to reflect their origin in different structures.

When the dendrochronological investigation was commissioned, it was suggested that this roof could be part of an unknown phase of construction from the sixteenth century, possibly related to a visit by Elizabeth I in AD 1575. This clearly cannot be the case for the roof structure as it presently stands, although, as noted above, two of the tiebeams and the wall plate could be part of such a phase. Instead this roof appears to have been constructed during the bishoprics of Babington, Parry, or Thornborough.

Chapel roof

Following its surrender during the Civil War, the castle was restored to the diocese in AD 1660. Repair work seems to have mostly been undertaken under Bishop Fleetwood (AD 1675–83) who certainly refitted the chapel with panelling, altar rail, and gallery (Molyneux pers comm). The chapel was subsequently refitted again in the period AD 1748–50 by

Bishop Maddox, with Hurd stating that Maddox 'put a new roof to it' (Molyneux pers comm). This later chapel includes a plaster fan-vaulted ceiling.

The present chapel roof is of queen strut design, with paired vertical posts supporting a collar, it is hipped to the east (Fig 6). The arrangement of the trusses does not respect the arrangement of the fan vaulting below. The four trusses over the chapel are identical to three more trusses in attic bedrooms with dormer windows immediately to the west. Two further east-west roofs, mostly in further attic rooms over the stair block and drawing room respectively, are of similar design and dimensions, whilst the east face of these blocks has a roof with another series of similar trusses, and dormer windows running north-south.

The chapel roof has been heavily defrassed, but fortunately this was done rather badly and some sapwood and bark-edge has survived. The roof contains a lot of relatively accessible timbers. A number of timbers were located with evidence for surviving sapwood. The eight samples include six from the area directly over the chapel, and two from the north-east corner of the drawing room block. The samples were obtained from two tiebeams, two principal rafters, and two hip-end timbers, all from over the chapel, and a principal rafter, and a common rafter from over the drawing room. Only one of these (sample 8, the north-east area common rafter) was found to be unsuitable for analysis. The remaining seven each yielded good sequences and all seven were cross-matched and dated. The 280-year composite sequence was found to strongly match to the material from the saloon and kitchen roofs at Hartlebury (Table 7), as well as to other composite sequences obtained from the vicinity (Table 10). It is thus most likely that these timbers were derived from the immediate vicinity of Hartlebury. This material comprised long-lived slow-growing oaks. The cross-dating indicated a later seventeenth century date for the datable timbers from these roofs.

Bark-edge survived on two of these timbers, some sapwood on another four, and the heartwood/sapwood boundary on the final datable sample. No allowance needs to be made for missing sapwood from the two complete samples, allowances for minimum and maximum likely amounts of missing sapwood provide individual felling date ranges for the other five datable timbers. Figure 9 and Table 1 include the interpreted felling dates, and felling date ranges for each of the datable samples.

The interpretation of this material is straightforward. The samples complete to bark edge both retain a complete ring for AD 1678, with no evidence for the onset of growth for the following year. These samples (a tiebeam over the chapel and a principal rafter in the north-east roof) were felled in the winter of AD 1678/9. The calculated felling date ranges for the remaining five samples indicated this material was either precisely or broadly contemporaneous.

These different areas of roof were therefore probably built shortly after felling in AD 1678 or 1679. This structure can therefore be associated with the extensively documented building works of Bishop Fleetwood.

Bell cupola

An octagonal bell cupola stands on the ridge at the centre of the aligned Great Hall and Parlour roof lines. It is aligned on the decorative doorway into the Great Hall and emphasises the pleasant symmetry of the structure. Hurd states that Maddox added this structure (Molyneux pers comm). The oak octagonal base frame of this structure is part of the floor of the inserted ceiling of the Great Hall, standing between trusses T5 and T6. From it rise the (presumably replacement) softwood posts of the cupola itself. The base frame timbers are neatly box-halved oak trees, neatly pegged and with short chisel-struck numbers. Visual similarities of the timbers suggested relatively few trees were needed in its construction (Fig 7). Six of the eight timbers forming this frame were sampled. All of these were found to be suitable for analysis, and these each yielded sequences which were cross-matched and dated. The 88-year composite sequence was found to match composite sequences from across England (Table 11), which is a common phenomenon for data of this period, so it is not certain, but nevertheless likely, that these timbers were derived from the vicinity of Hartlebury. This material comprised relatively short-lived and medium growth-rate oaks. The cross-dating indicated a mid-eighteenth-century date for the datable timbers from this framework.

Bark-edge survived on none of these timbers, some unusually large amounts of sapwood were present on two (in both cases including additional detached fragments), less sapwood on another two, and the remaining two samples were heartwood only. Allowances for minimum and maximum likely amounts of missing sapwood provide individual felling date ranges, or *terminus post quem* dates, for the six sampled timbers. Figure 9 and Table 1 include the felling date ranges or *terminus post quem* dates for each of these samples.

The calculation of the common felling period for each sampled timber from this roof suggests a construction date between AD 1749 and *c* AD 1754. The mathematical combination of estimated sapwood distributions is statistically complex, and to achieve a tighter interpretation would require reliable sapwood data for the area, period, and the specific character of these oaks. Such data are not presently available. In fact, the remarkably different sapwood values present on this material illustrate the general problem of calculating reliable sapwood estimates: these timbers are of similar age, geographic origin, growth rates, and period, yet, if we assume they were felled at the same time, they have completely different amounts of sapwood. The contemporaneous sampling notes provide strong support for the proximity of the bark-edges on the two timbers with the latest rings, and not in the other material. Until the point that the sapwood models can deal with this kind of assemblage, the use of robust combinatorial methods, or alternative statistical approaches, would in this case probably suggest the material is derived from two separate periods, for which there is no other suggestion or evidence. The material appears to have been used green, so this is not an issue associated with stockpiling. So it is most likely that this frame utilises timbers felled in the middle years of the eighteenth century.

This result suggests this base frame was built shortly after AD 1749. This structure can therefore be firmly associated with the building works of Bishop Maddox (AD 1743–59), as was recorded by Bishop Hurd.

The Hurd Library roof

One final area was on the dating commission. This is the roof of the library which was purpose-built (*c* AD 1782) to house Bishop Hurd's large collection of books. This room was built as a long gallery on the west side of the castle. During the initial assessment visit no route for accessing this space was located; there are no hatches in the library, or in the vestibules at either end, nor are there roof hatches into it from above. However, during the sampling in the saloon roof, a dormer-like linking roof was noticed which gives direct access to the roof of this room. Here is a simple oak roof, of king-post form, with joggled raking braces (Fig 8). The timbers were derived from small young fast-growing oaks, that were carefully assessed but were deemed unsuitable for sampling and analysis.

REFERENCES

Arnold, A, Howard, R, and Litton, C, 2006a *The Commandery, Worcester: tree-ring analysis of timbers*, EH Res Dept Rep Ser, **71/2006**

Arnold, A, Howard, R, and Litton, C, 2006b *The Guildhall Complex and Pedagogue's House, Stratford-upon-Avon, Warwickshire: tree-ring analysis of timbers*, EH Res Dept Rep Ser, **68/2006**

Arnold, A, Howard, R, and Litton, C, 2006c *Kingsbury Hall, Kingsbury, Warwickshire: tree-ring analysis of timbers*, EH Res Dept Rep Ser, **53/2006**

Arnold, A J, Howard, R E, and Litton, C D, 2004 *Tree-ring analysis of oak timbers from the Chapter House, Worcester Cathedral, Worcester*, Centre for Archaeol Rep, **65/2004**

Baillie, M G L, and Pilcher, J R, 1973 A simple crossdating program for tree-ring research, *Tree Ring Bull*, **33**, 7–14

Barefoot, A C, 1975 A Winchester dendrochronology for 1635–1972 AD – its validity and possible extension, *J Inst Wood Sci*, **7**(1), 25–32

Bridge, M C, 2002 *Tree-ring analysis of timbers from Ashleworth Tithe Barn, Quay Lane, Gloucestershire*, Centre for Archaeol Rep, **17/2002**

English Heritage, 1998 *Dendrochronology: guidelines on producing and interpreting dendrochronological dates*, London

Groves, C, 2002 *Dendrochronological analysis of Bowhill, Exeter, Devon*, Centre for Archaeol Rep, **23/2002**

Groves, C, and Hillam, J, 1993 *Tree-ring analysis of oak timbers from the medieval barn, King's Pyon, near Leominster, Hereford and Worcester, 1992 – interim report*, Anc Mon Lab Rep, **24/93**

Groves, C, and Hillam, J, 1997 Tree-ring analysis and dating of timbers, in *A multi-period salt production site at Droitwich: Excavations at Upwich* (J D Hurst), CBA Res Rep, **107**, 121–6

Howard, R, Litton, C, and Arnold, A, 2006 *Guildhall, High Street, Worcester: tree-ring analysis of timbers*, EH Res Dept Rep Ser, **42/2006**

Howard, R E, Laxton, R R, and Litton, C D, 1996 *Tree-ring analysis of timbers from Mercer's Hall, Mercer's Lane, Gloucester*, Anc Mon Lab Rep, **13/96**

Howard, R E, Laxton, R R, and Litton, C D, 1998a *Tree-ring analysis of timbers from 26 Westgate Street, Gloucester*, Anc Mon Lab Rep, **43/98**

Howard, R E, Laxton, R R, and Litton, C D, 1998b *Tree-ring analysis of timbers from Chicksands Priory, Chicksands, Bedfordshire*, Anc Mon Lab Rep, **30/98**

Nayling, N, 1999 *Tree-ring analysis of timbers from the White House, Vowchurch, Herefordshire*, Anc Mon Lab Rep, **73/1999**

Nayling, N, 2001 *Tree-ring analysis of timbers from Lower Brockhampton Gatehouse, near Bromyard, Herefordshire*, Centre for Archaeol Rep, **98/2001**

Tyers, I, 1998a *Tree-ring analysis of oak timbers from St Nicholas' Church, Warndon, Worcestershire*, Anc Mon Lab Rep, **34/98**

Tyers, I, 1998b *Tree-ring analysis of oak timbers from the "Brewhouse" and "Refectory" at Nostell Priory, near Wakefield, West Yorkshire*, Anc Mon Lab Rep, **20/98**

Tyers, I, 1999 *Dendrochronological analysis of timbers from Black Ladies, near Brewood, Staffordshire*, ARCUS Rep, **484**

Tyers, I, 2000a *Tree-ring analysis of oak timbers from the church of St Swithin, Clunbury, Shropshire*, Anc Mon Lab Rep, **8/2000**

Tyers, I, 2000b *Tree-ring spot-dates and wood identifications from the Royal Arsenal, Woolwich*, ARCUS Rep, **559**

Tyers, I, 2001 *Dendrochronological analysis of timbers from New House Grange Tithe Barn, Sheepy Magna, Leicestershire*, ARCUS Rep, **574d**

Tyers, I, 2002 *Tree-ring analysis of oak timbers from the Abbot's Hall and Parlour at Wigmore Abbey, near Adforton, Herefordshire*, Centre for Archaeol Rep, **112/2002**

Tyers, I, 2003 *The tree-ring analysis of the Bellframe at the church of St Bartholomew the Less, London EC1*, ARCUS Rep, **717g**

Tyers, I, 2004 *Dendro for Windows program guide 3rd edn*, ARCUS Rep, **500b**

Tyers, I, 2007a *The tree-ring dating of 3 timber framed buildings in Weobley, Herefordshire*, Dendro Co Rep, **22**

Tyers, I, 2007b *The tree-ring dating of 8 buildings in Wribbenhall, Worcestershire*, Dendro Co Rep, **9**

Tyers, I, 2008a *Tree-ring analysis of timbers from a building: Tickenhill Manor, Bewdley, Worcestershire*, Dendro Co Rep, **124**

Tyers, I, 2008b *The tree-ring dating of buildings in Whitbourne, Herefordshire*, Dendro Co Rep, **42**

Tyers, I, and Groves, C, 1997 *Dendrochronological analysis of timbers from Poole's Wharf, Hotwells, Bristol*, ARCUS Rep, **303**

Tyers, I, and Wilson, R, 2000 Tree-ring analysis of oak timbers from 66 and 68 Westgate Street, Gloucester, Anc Mon Lab Rep, **19/2000**

FIGURES

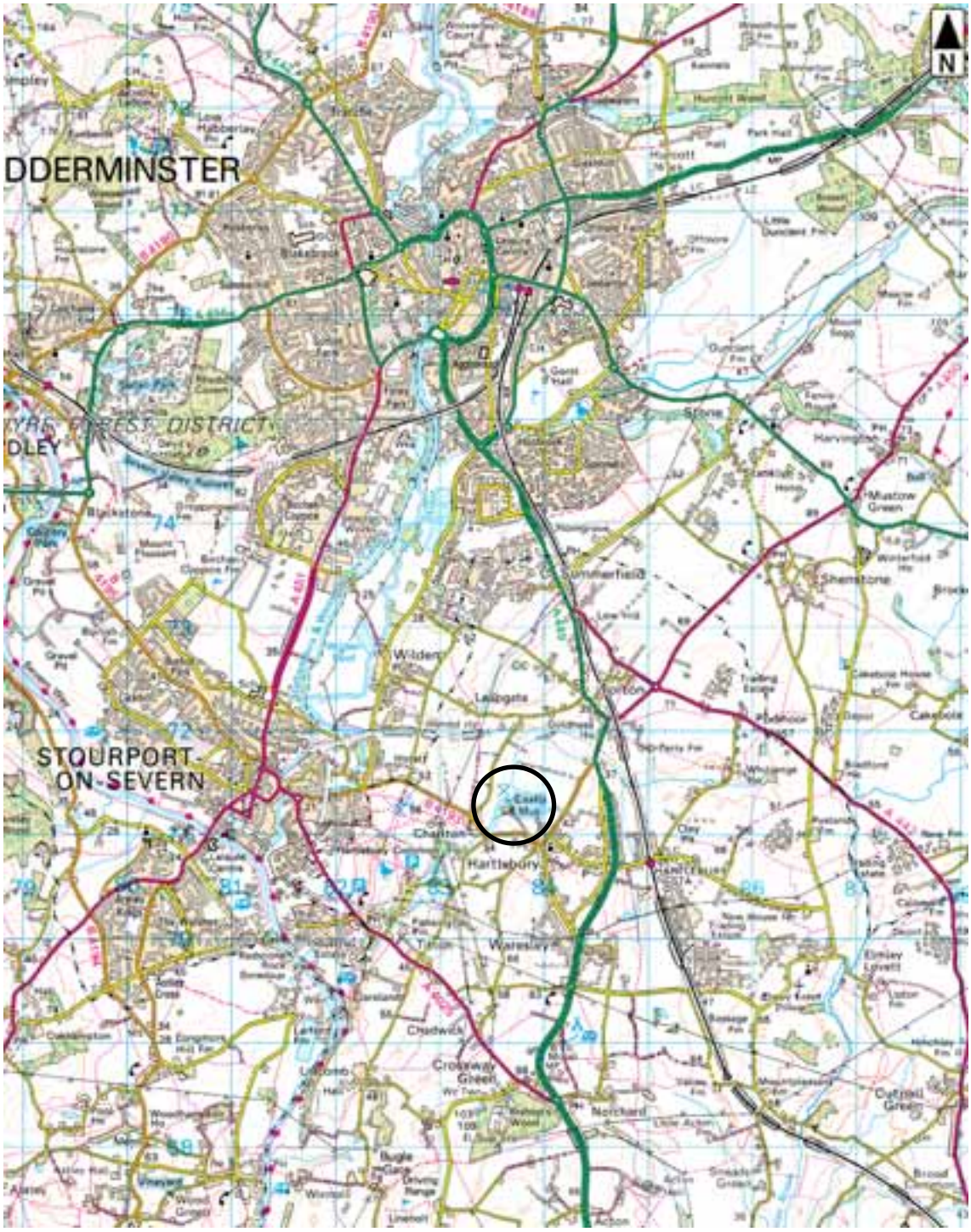

Figure 1. Location of Hartlebury Castle (circled). © Crown Copyright. All rights reserved. English Heritage 100019088. 2009

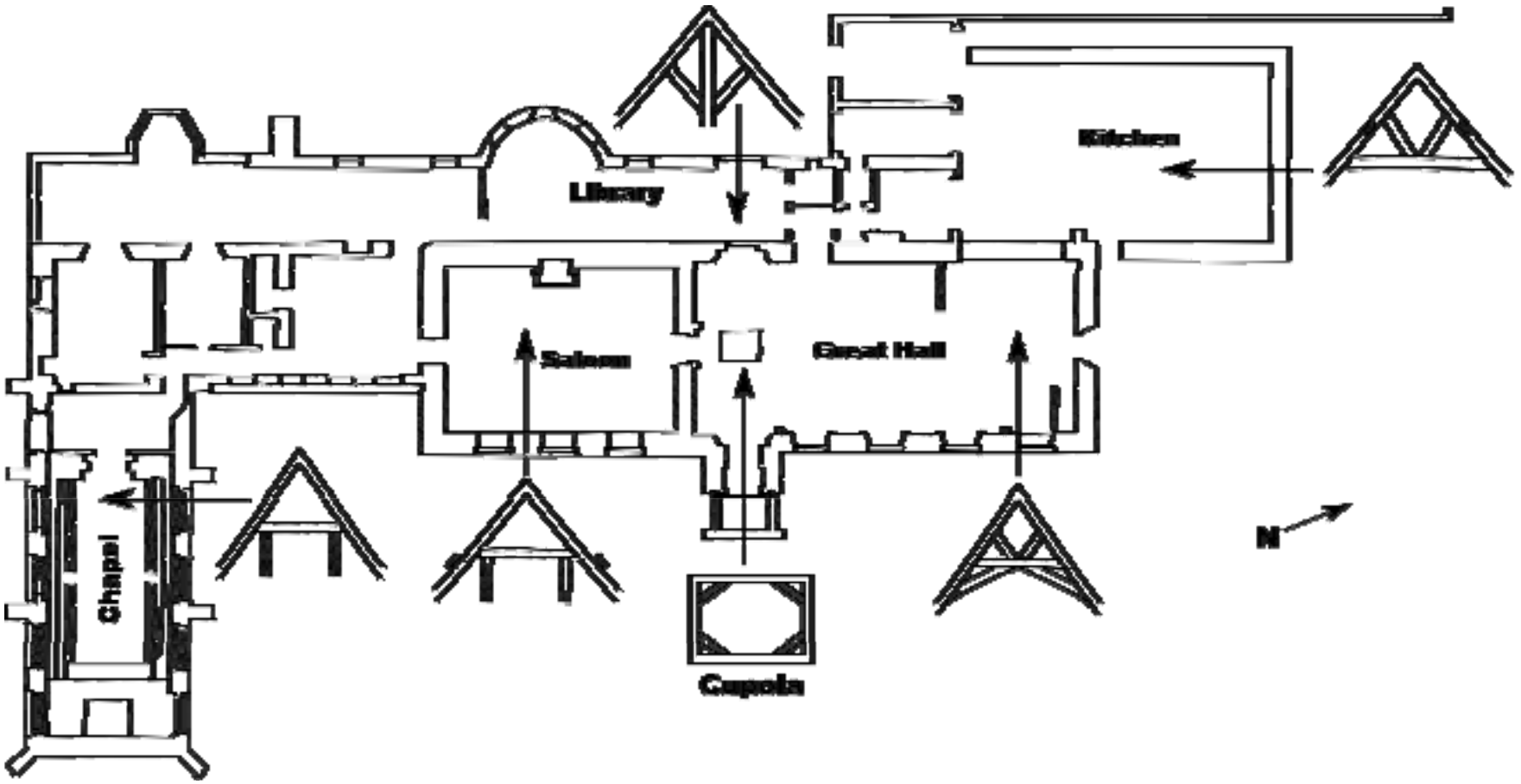

Figure 2. Plan of Hartlebury Castle showing the location of the areas discussed in this report. Based on a plan supplied by EH

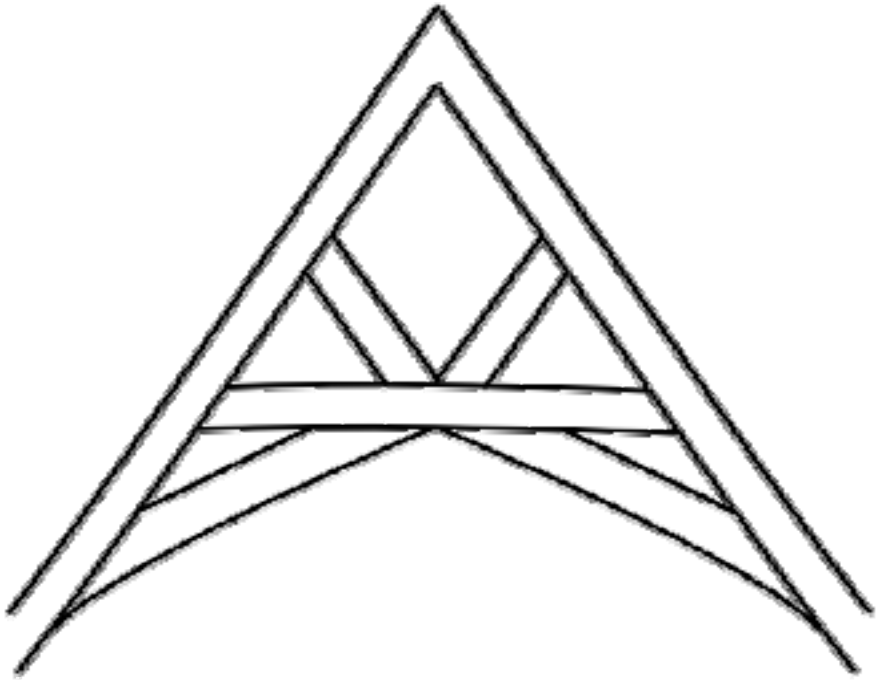

Figure 3. Great Hall roof truss (schematic representation). Figure supplied by English Heritage

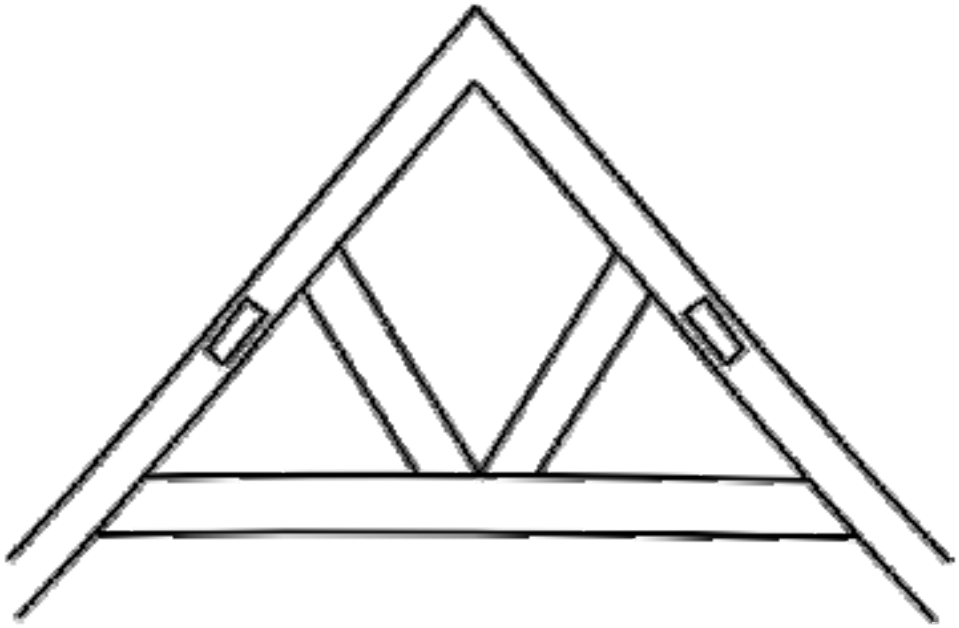

Figure 4. Kitchen roof truss (schematic representation). Figure supplied by English Heritage

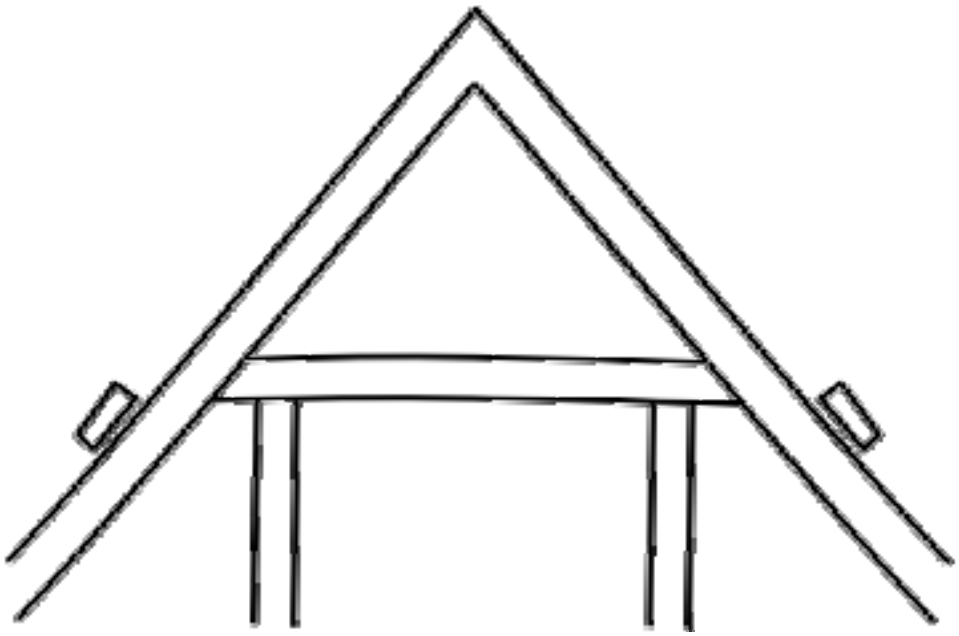

Figure 5. Saloon truss (schematic representation). Figure supplied by English Heritage

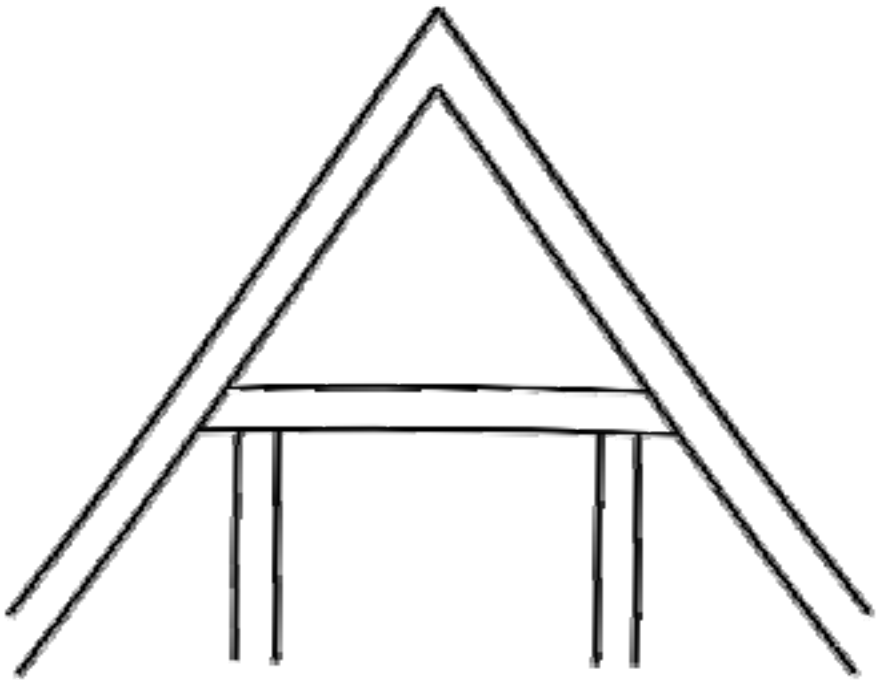

Figure 6. Chapel roof truss (schematic representation). Figure supplied by English Heritage

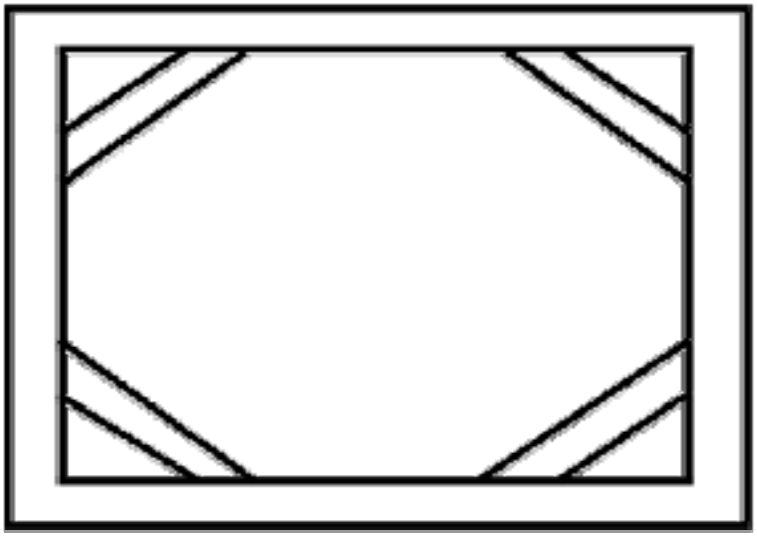

Figure 7. Bell cupola base frame (schematic representation). Figure supplied by English Heritage

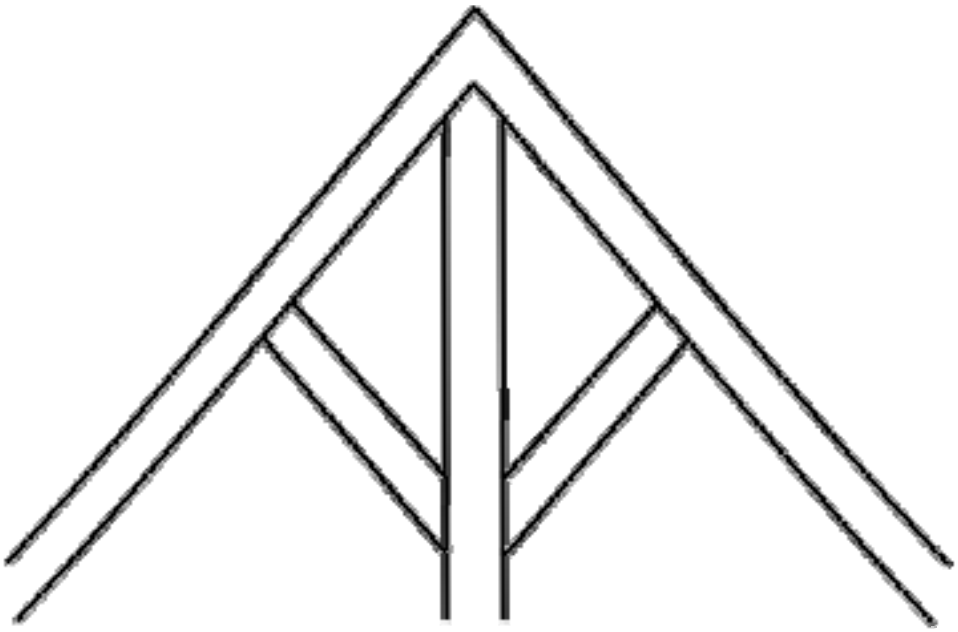

Figure 8. Hurd library truss (schematic representation). Figure supplied by English Heritage

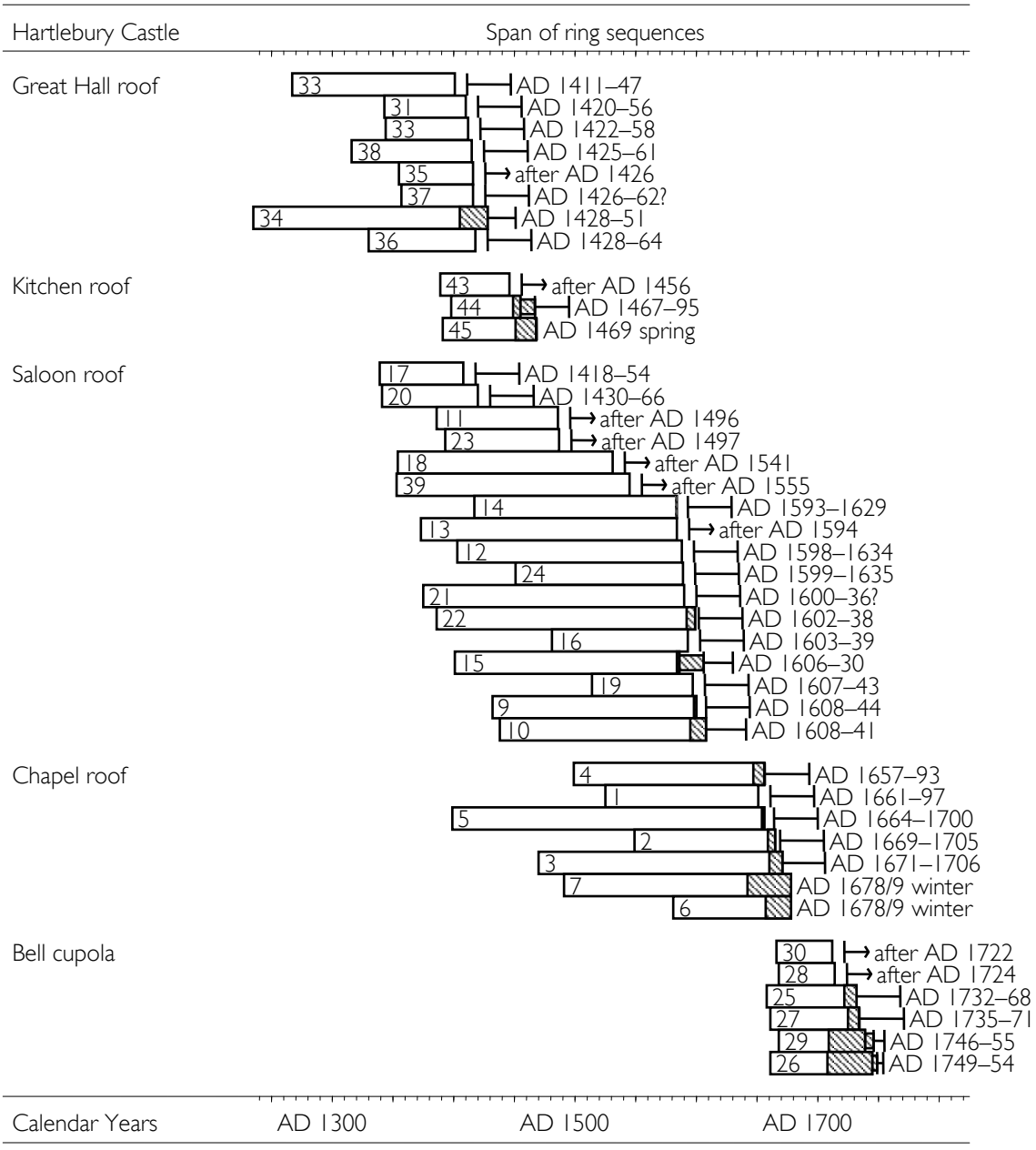

Figure 9. Bar diagram showing the absolute dating positions of the 41 dated tree-ring sequences for samples from Hartlebury Castle. The interpreted felling dates are also shown for each sample

KEY White bars are oak heartwood, hatched bars are sapwood, the narrow bars represent unmeasured sapwood

TABLES

Table 1. Details of the 45 samples from timbers from Hartlebury Castle

Sample	Location	Rings	Sap	Date of measured sequence	Interpreted result
1	CR lower hip purlin	127	H/S	AD 1525–1651	AD 1661–97
2	CR hip principal	117	6	AD 1549–1665	AD 1669–1705
3	CR T2 tiebeam	202	11	AD 1470–1671	AD 1671–1706
4	CR T2 S principal	158	9	AD 1499–1656	AD 1657–93
5	CR T3 N principal	258	2	AD 1399–1656	AD 1664–1700
6	CR T4 tiebeam	98	21+Bw	AD 1581–1678	AD 1678 winter
7	CR NE S principal	188	36+Bw	AD 1491–1678	AD 1678 winter
8	CR NE rafter 2	-	-	unmeasured	-
9	SA T5 W principal	169	2	AD 1432–1600	AD 1608–44
10	SA T5 E principal	171	13	AD 1438–1608	AD 1608–41
11	SA T5 tiebeam	101	-	AD 1386–1486	after AD 1496
12	SA T4-5 E purlin	186	H/S	AD 1403–1588	AD 1598–1634
13	SA T4 tiebeam	212	-	AD 1373–1584	after AD 1594
14	SA T4 W principal	168	1	AD 1417–1584	AD 1593–1629
15	SA T4-5 W purlin	186	2+*20*	AD 1401–1586	AD 1606–30
16	SA T3 tiebeam	113	H/S	AD 1481–1593	AD 1603–39
17	SA T1 queen strut	70	H/S	AD 1339–1408	AD 1418–54
18	SA T3 W principal	178	-	AD 1354–1531	after AD 1541
19	SA T5 E rafter 2	84	H/S	AD 1514–1597	AD 1607–43
20	SA T5 E rafter 1	80	H/S	AD 1341–1420	AD 1430–66
21	SA T2 tiebeam	216	?H/S	AD 1375–1590	AD 1600–36?
22	SA T2 W principal	214	7	AD 1386–1599	AD 1602–38
23	SA T1 tiebeam	95	-	AD 1393–1487	after AD 1497
24	SA T1 lower collar	139	H/S	AD 1451–1589	AD 1599–1635
25	BC E joist	75	10	AD 1658–1732	AD 1732–68
26	BC SE brace	85	37+*4*	AD 1661–1745	AD 1749–54
27	BC S stretcher	74	9	AD 1661–1734	AD 1735–71
28	BC SW brace	47	-	AD 1668–1714	after AD 1724
29	BC NW brace	72	30+*7*	AD 1668–1739	AD 1746–55
30	BC N stretcher	47	-	AD 1666–1712	after AD 1722
31	GH T6 W principal	68	H/S	AD 1343–1410	AD 1420–56
32	GH T6 E principal	69	H/S	AD 1344–1412	AD 1422–58
33	GH T6 E V-strut	135	H/S	AD 1267–1401	AD 1411–47
34	GH T5 W principal	194	23	AD 1235–1428	AD 1428-51
35	GH T4-5 W purlin	62	-	AD 1355–1416	after AD 1426
36	GH T4-5 E purlin	89	H/S	AD 1330–1418	AD 1428–64
37	GH T3-4 E purlin	60	?H/S	AD 1357–1416	AD 1426–62?
38	GH T2 W V-strut	100	H/S	AD 1316–1415	AD 1425–61
39	SA T3-4 W plate	193	-	AD 1353–1545	after AD 1555

Table 1 (continued)

Sample	Location	Rings	Sap	Date of measured sequence	Interpreted result
40	KI E principal	-	-	unmeasured	-
41	KI SE lower purlin	-	-	unmeasured	-
42	KI E lower purlin	-	-	unmeasured	-
43	KI collar	58	-	AD 1389–1446	after AD 1456
44	KI E V-strut	58	6+*12*	AD 1398–1455	AD 1467–95
45	KI W V-strut	78	17+Bs	AD 1391–1468	AD 1469 spring

KEY For locations see Figure 2. GH; Great Hall roof, trusses T1–6 from north. KI; Kitchen roof, southernmost truss; SA Saloon roof, trusses T1–5 from south. CR; Chapel roof, T1–4 from east. BC; Bell cupola base frame. N north, S south, E east, W west, H/S is heartwood/sapwood edge, Bw bark after complete ring, Bs bark after incomplete additional annual ring, *italics* gives the estimated numbers of unmeasured sapwood rings.

Table 2. The t-values (Baillie and Pilcher 1973) between the 8 sampled timbers from the Great Hall roof (samples 31–8) from Hartlebury Castle. – t-value less than 3.0

	32	33	34	35	36	37	38
31	3.68	3.30	-	4.70	3.98	3.58	3.03
32		-	3.05	-	3.54	4.13	-
33			4.93	-	-	-	3.55
34				-	-	3.42	-
35					-	3.26	-
36						3.53	-
37							-

Table 3. The t-values (Baillie and Pilcher 1973) between 3 sampled timbers from the Kitchen roof (samples 43–5) from Hartlebury Castle.

	44	45
43	4.80	4.47
44		4.78

Table 4. The t-values (Baillie and Pilcher 1973) between the 17 sampled timbers from the Saloon roof (samples 9–24 and 39) from Hartlebury Castle. – t-value less than 3.0, \ no or short overlap.

	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	39
9	10.66	3.23	7.45	5.93	-	7.61	9.51	\	6.36	4.80	\	12.57	6.46	-	6.69	-
10		3.66	9.16	4.96	-	4.13	6.12	\	4.91	3.96	\	8.40	6.44	-	5.96	-
11			5.39	5.31	5.50	6.05	\	-	8.82	\	6.95	5.02	4.33	6.10	3.35	4.63
12				5.61	5.73	5.49	6.68	\	6.20	4.85	-	8.29	10.79	4.43	6.92	3.03
13					4.68	5.27	-	4.24	6.50	-	3.26	6.67	5.50	4.18	5.35	4.67
14						7.09	3.23	\	5.56	6.75	\	3.67	3.63	6.80	3.31	8.38
15							4.52	\	7.44	5.39	4.21	6.52	4.19	5.90	3.69	6.62
16								\	-	3.70	\	7.53	5.13	\	7.38	-
17									4.74	\	6.88	3.13	-	-	\	-
18										-	5.02	6.09	5.41	5.75	3.53	4.89
19											\	3.30	-	\	-	4.96
20												3.13	-	3.16	\	-
21													8.22	4.77	10.61	4.48
22														5.13	8.50	-
23															-	6.53
24																-

Table 5. The t-values (Baillie and Pilcher 1973) between 7 sampled timbers from the Chapel roofs (samples 1–7) from Hartlebury Castle.

	2	3	4	5	6	7
1	7.42	6.47	8.18	7.51	4.41	7.03
2		7.54	5.87	6.69	7.06	5.47
3			9.55	8.39	5.02	7.88
4				10.54	4.18	7.18
5					4.46	9.13
6						3.76

Table 6. The t-values (Baillie and Pilcher 1973) between the 6 sampled timbers from the Bell cupola (samples 25–30) from Hartlebury Castle.

	26	27	28	29	30
25	7.56	8.33	7.04	6.96	6.66
26		7.13	9.12	9.50	6.27
27			5.76	5.90	13.82
28				8.01	5.50
29					5.28

Table 7. The t-values (Baillie and Pilcher 1973) between the 5 composite sequences constructed from timbers from the sampled areas of Hartlebury Castle. – t-value less than 3.0, \ no or short overlap.

	Kitchen roof	Saloon roof	Chapel roof	Bell cupola
Great Hall roof	3.09	8.64	-	\
Kitchen roof		6.08	6.19	\
Saloon roof			11.88	\
Chapel roof				4.09

Table 8. Showing example t-values (Baillie and Pilcher 1973) between the composite sequence constructed from the Great Hall samples at Hartlebury Castle and oak reference data.

Reference chronology	Hartlebury Great Hall AD 1235–1428
Devon, Exeter Bowhill (Groves 2002)	7.36
Gloucestershire, 66/68 Westgate St Gloucester (Tyers and Wilson 2000)	10.75
Gloucestershire, Ashleworth Tithe Barn (Bridge 2002)	7.97
Herefordshire, Wigmore Abbey (Tyers 2002)	8.16
Warwickshire, Guildhall Stratford upon Avon (Arnold *et al* 2006b)	8.06
Worcestershire ,The Commandery Worcester (Arnold *et al* 2006a)	7.82
Worcestershire, Warndon church (Tyers 1998a)	7.62
Worcestershire, Worcester Cathedral (Arnold *et al* 2004)	11.36

Table 9. Showing example t-values (Baillie and Pilcher 1973) between the composite sequence constructed from the Kitchen samples at Hartlebury Castle and oak reference data.

Reference chronology	Hartlebury Kitchen AD 1389–1468
Gloucestershire, Gloucester Mercers Hall (Howard *et al* 1996)	7.55
Herefordshire, Kings Pyon barn (Groves and Hillam 1993)	6.82
Herefordshire, Weobley Broad St (Tyers 2007a)	6.41
Herefordshire, Whitbourne Ring o' Bells/Virginia Cottage (Tyers 2008b)	6.46
Leicestershire, New House Grange Barn Sheepy Magna (Tyers 2001)	6.34
London, St Barts the Less bellframe (Tyers 2003)	6.89
Worcestershire, The Commandery Worcester (Arnold *et al* 2006a)	6.33
Worcestershire, Tickenhill Manor (Tyers 2008a)	6.23

Table 10. Showing example t-values (Baillie and Pilcher 1973) between the composite sequences constructed from the Saloon roof and Chapel roof samples at Hartlebury Castle and oak reference data.

Reference chronology	Hartlebury Saloon roof AD 1339–1608	Hartlebury Chapel roof AD 1399-1678
Gloucestershire, Gloucester 26 Westgate Street (Howard *et al* 1998a)	13.81	14.96
Herefordshire, Lower Brockhampton Gatehouse (Nayling 2001)	11.93	10.78
Herefordshire, White House Vowchurch (Nayling 1999)	10.31	10.52
Staffordshire, Black Ladies nr Brewood (Tyers 1999)	10.53	10.43
Warwickshire, Kingsbury Hall (Arnold *et al* 2006c)	11.03	10.79
Worcestershire, Hoarstone Farm (Tyers 2008)	13.21	12.79
Worcestershire, Worcester The Guildhall (Howard *et al* 2006)	10.89	10.89
Worcestershire, Wribbenhall 3 Beales Corner (Tyers 2007b)	12.63	11.33

Table 11. Showing example t-values (Baillie and Pilcher 1973) between the composite sequence constructed from the Bell cupola samples at Hartlebury Castle and oak reference data.

Reference chronology	Hartlebury Bell cupola AD 1658–1745
Avon, Bristol Pooles Wharf (Tyers and Groves 1997)	5.92
Bedfordshire, Chicksands Priory (Howard *et al* 1998b)	6.50
London, HMS Victory (Barefoot 1975)	9.22
London, Royal Arsenal Woolwich (Tyers 2000b)	6.44
Shropshire, Clunbury Church nr Ludlow (Tyers 2000a)	5.29
Worcestershire, Droitwich Upwich (Groves and Hillam 1997)	7.24
Worcestershire, Worcester Cathedral (Arnold *et al* 2004)	9.26
Yorkshire, Nostell Priory nr Wakefield (Tyers 1998b)	7.01

APPENDIX 1

hbc1

262	233	211	247	216	203	365	238	211	217
319	256	317	366	306	285	279	184	247	237
201	153	98	153	196	227	247	177	196	195
259	133	83	75	94	111	118	129	80	117
71	61	84	86	110	162	144	85	95	66
105	102	117	89	91	114	113	91	84	107
108	132	125	113	125	90	77	99	106	120
124	126	100	102	104	92	98	124	113	128
97	92	109	102	100	98	84	73	81	73
61	65	81	123	77	88	112	128	103	79
56	75	131	89	109	123	91	102	106	72
68	50	66	83	83	65	86	92	105	135
125	95	78	89	88	93	75			

hbc2

177	162	205	142	157	158	156	104	94	76
110	180	124	165	91	110	91	62	77	75
177	167	160	95	70	55	54	60	86	98
160	267	209	197	205	215	244	190	214	155
196	122	111	145	165	238	250	281	222	185
123	128	155	248	217	198	152	164	134	134
94	89	121	102	111	138	91	82	94	137
128	157	189	206	166	109	88	91	143	156
157	174	176	261	378	215	319	257	328	399
311	318	299	406	315	317	242	259	219	239
236	222	152	116	119	107	172	191	192	212
165	132	94	99	200	182	124			

hbc3

167	168	103	130	169	144	105	87	92	98
128	113	88	90	94	78	69	95	70	76
109	88	75	94	116	111	137	130	121	135
81	48	40	40	55	113	94	67	76	112
112	157	163	179	131	121	109	93	144	226
136	132	138	129	118	116	95	90	109	149
122	172	129	134	132	179	191	142	135	169
181	168	118	148	178	215	162	104	120	122
135	172	118	156	134	172	116	75	84	96
168	184	242	147	167	81	78	37	61	76
86	105	106	54	59	41	47	57	49	58
238	253	221	156	212	293	239	200	136	158
84	94	110	120	123	125	103	99	94	63
56	92	101	97	120	77	81	70	68	52
64	60	47	88	84	63	51	69	94	85
124	150	172	170	125	88	83	105	113	174
134	125	151	156	121	122	111	116	207	159
168	150	168	147	135	142	153	157	166	164
154	131	91	105	81	176	138	172	160	120
143	160	156	222	204	228	193	168	252	173
166	185								

hbc4

296	325	295	209	234	261	328	268	295	221
213	204	221	184	165	112	157	109	72	107
226	117	182	258	225	163	151	178	189	232
199	138	192	170	143	133	203	203	158	158
154	156	151	112	147	176	165	97	82	97
110	137	161	93	124	118	158	141	110	65
75	98	146	172	117	154	146	96	77	106
127	134	161	116	124	128	126	113	122	89
106	148	162	124	101	130	157	126	116	119
148	103	100	91	141	121	150	129	124	117
115	97	128	135	136	161	110	128	114	124
116	117	111	110	146	111	117	116	114	132
98	126	142	181	122	96	93	109	114	97
157	124	100	127	130	95	100	79	90	103
99	96	106	113	99	113	108	93	107	114
121	110	122	113	90	83	123	126		

hbc5

165	95	100	40	117	83	58	48	44	51
88	63	51	55	46	41	52	47	52	69
42	103	77	45	69	63	58	56	51	85
63	56	51	89	53	65	81	61	75	75
63	68	84	47	45	73	75	49	56	63
66	50	97	60	61	80	66	73	65	73
43	90	60	44	60	42	48	49	45	76
125	161	124	79	80	87	197	136	104	102
147	127	132	144	145	115	135	111	153	111
104	117	115	80	101	109	90	117	106	65
91	92	74	69	84	79	101	87	84	101
99	100	83	83	103	83	113	65	55	78
123	64	70	94	94	81	62	65	79	98
78	63	95	71	74	58	103	70	74	71
65	71	81	53	76	85	59	61	51	48
87	79	96	58	72	64	108	60	57	55
58	92	79	101	68	96	59	49	44	59
110	92	98	69	80	72	74	77	78	86
72	120	101	71	73	105	121	92	113	109
134	73	84	69	81	78	107	94	73	79
88	65	83	100	97	81	56	89	74	88
65	73	57	57	126	87	58	57	77	83
66	68	87	89	47	58	49	68	65	55
85	69	97	153	115	65	81	53	74	129
106	99	81	110	92	83	68	91	73	94
62	86	59	74	57	49	95	77		

hbc6

199	167	169	179	202	159	220	201	236	141
151	158	186	151	158	190	154	154	167	134
160	210	176	170	148	167	157	165	156	151
144	117	130	127	119	127	155	141	121	136
148	186	157	125	129	96	165	166	171	138
110	132	153	113	126	98	127	149	115	129
104	100	91	111	87	99	105	115	86	108
83	81	93	94	122	103	103	116	94	111
90	117	154	143	128	121	149	142	118	117
161	145	135	101	120	114	149	150		

hbc7

61	62	78	69	91	154	99	86	79	65
56	56	44	42	42	33	30	54	78	72
92	81	79	67	88	51	37	40	72	46
47	41	33	36	38	23	49	68	61	52
69	71	77	84	137	101	135	129	112	116
93	64	79	118	121	114	73	75	88	84
116	70	81	63	86	62	51	48	39	36
39	47	43	57	26	15	19	28	35	52
46	31	26	24	20	18	32	36	47	61
51	39	29	40	47	49	52	53	44	48
39	48	59	70	79	72	43	45	41	50
56	73	72	103	71	80	68	48	54	61
64	59	72	52	39	38	44	60	44	48
57	50	44	45	24	27	31	32	65	47
37	75	60	46	55	28	31	41	48	44
46	50	47	36	35	45	38	39	38	41
34	28	37	25	59	47	44	29	30	34
28	26	34	44	36	31	35	48	30	29
34	43	43	31	26	31	55	40		

hbc9

193	164	143	178	136	120	82	83	95	116
85	144	218	137	107	136	189	171	128	147
148	160	181	190	183	192	209	149	163	142
164	160	93	155	180	273	220	288	268	258
282	308	309	409	325	304	233	271	172	261
217	256	295	240	323	235	235	177	177	165
140	240	178	126	305	172	189	179	150	162
133	151	188	167	186	162	105	155	155	128
166	153	134	159	117	142	154	165	117	126
172	174	109	114	133	140	160	136	140	194
122	216	199	247	281	182	202	200	166	306
143	300	222	230	171	158	213	243	290	381
277	244	261	305	198	181	177	211	187	190
162	111	198	150	102	90	119	202	201	230
185	207	141	124	118	123	105	127	169	162
145	130	174	233	191	185	138	67	44	65
78	78	124	104	110	80	87	112	83	

hbc10

90	61	82	107	106	108	186	116	104	95
109	114	97	136	127	134	159	149	129	166
154	94	109	91	123	118	73	92	116	159
145	171	200	127	167	157	182	287	249	164
152	158	113	138	104	88	129	102	123	126
104	97	97	112	127	128	122	182	516	379
296	279	190	172	195	223	263	203	197	148
119	81	49	61	94	75	76	69	86	84
79	83	77	72	96	66	76	65	70	63
64	62	53	85	63	82	96	96	98	101
109	116	133	235	118	176	143	131	116	133
159	259	290	381	277	321	250	300	192	155
143	181	156	162	82	75	95	108	67	74
115	159	115	147	137	137	105	117	101	100
79	112	173	167	112	98	147	192	162	173
127	86	71	92	80	98	115	136	79	74
82	116	101	137	112	122	118	94	74	113
108									

hbc11

111	93	78	103	82	103	92	72	84	92
109	101	130	146	149	168	104	127	147	123
127	122	108	121	124	117	110	85	97	121
114	107	118	64	116	94	83	115	106	90
80	99	108	85	148	107	116	99	103	128
116	114	113	80	103	148	88	98	125	131
103	104	100	113	114	165	119	116	136	113
142	110	145	110	206	155	151	117	78	110
112	139	174	213	213	173	229	180	190	185
167	128	96	131	140	159	133	124	129	203
190									

hbc12

91	73	90	104	83	99	125	119	92	86
98	95	155	209	196	170	112	142	128	132
174	133	151	145	139	168	161	136	152	139
114	110	122	116	88	68	59	98	126	113
124	133	117	110	101	91	87	93	107	102
96	129	121	129	108	119	95	128	86	106
106	90	98	99	110	131	149	140	100	154
125	150	213	172	147	152	184	160	172	112
135	127	144	121	112	120	102	109	113	93
115	60	57	113	120	114	135	100	83	89
87	109	78	92	60	47	75	74	97	143
105	74	84	82	107	91	112	88	84	84
71	79	67	67	79	96	71	85	77	78
78	96	71	104	92	88	92	103	147	99
111	92	90	78	84	107	127	168	245	158
237	211	192	181	131	118	108	121	134	165
156	170	159	111	89	150	188	118	165	121
133	97	104	84	113	86	117	136	149	139
110	141	165	158	216	186				

hbc13

116	138	111	148	145	143	203	130	127	137
142	175	146	176	135	139	115	106	124	107
105	78	63	55	79	107	126	131	132	95
136	123	121	98	91	101	128	108	117	106
92	111	118	107	112	102	98	93	100	90
124	101	115	98	121	120	114	121	150	151
133	141	126	106	89	86	63	93	119	84
105	111	112	109	96	114	104	100	97	99
87	120	98	97	121	109	85	106	86	98
101	60	106	108	113	121	123	113	97	110
102	110	112	99	104	136	162	131	139	123
105	101	119	119	116	121	145	172	130	107
128	130	108	134	104	103	134	98	70	60
77	78	76	71	63	75	75	67	54	69
72	67	72	63	81	80	84	77	83	85
83	77	66	62	71	75	81	76	90	90
94	91	109	104	95	99	89	103	104	94
116	114	85	85	94	85	104	81	109	90
97	89	86	80	70	71	61	69	78	67
71	69	70	55	57	72	77	82	74	80
77	76	68	65	69	70	79	84	81	86
76	94								

hbc14

132	127	108	144	143	107	158	136	148	123
111	161	154	182	172	174	143	158	171	136
113	147	109	203	200	144	183	177	232	223
135	132	100	159	231	140	126	134	127	178
141	147	128	184	137	130	139	97	118	159
139	185	200	303	190	180	197	189	286	148
171	148	188	217	215	229	180	175	197	162
216	165	157	164	148	101	131	151	142	146
134	135	183	142	137	129	97	95	135	142
131	113	164	162	161	164	111	79	148	95
107	119	122	115	93	161	93	116	79	54
51	86	63	54	48	42	42	47	46	42
32	40	44	52	60	57	48	52	57	50
51	50	59	56	67	56	67	59	81	84
68	65	69	95	96	127	91	89	94	78
68	83	126	106	115	114	146	136	129	96
102	99	98	173	138	142	101	134		

hbc15

109	73	106	88	81	120	87	85	99	78
60	58	66	82	83	80	70	80	55	69
79	68	95	93	75	78	105	114	97	101
88	92	59	76	83	85	60	57	55	69
72	58	67	87	81	67	64	73	59	49
75	48	58	71	69	76	64	64	44	74
59	91	97	60	94	95	122	121	125	109
95	99	89	74	108	98	99	117	143	116
133	155	116	104	120	131	107	117	107	122
141	97	161	171	107	108	118	87	95	84
114	151	107	112	227	176	177	135	219	214
192	182	202	122	100	100	160	187	215	164
122	163	101	115	105	101	120	161	134	104
143	106	152	126	143	120	90	92	97	100
98	63	66	82	85	72	63	67	94	93
81	55	62	68	100	64	53	55	76	85
85	93	77	116	121	64	60	76	104	103
108	93	110	107	80	81	95	110	97	135
113	152	117	121	133	120				

hbc16

140	112	153	208	156	177	119	128	111	135
123	110	157	110	137	181	165	177	178	122
151	139	142	178	161	135	118	89	111	80
103	102	85	82	90	80	89	98	88	63
84	101	99	79	79	72	76	80	81	67
95	82	101	101	118	142	112	105	95	121
155	101	129	128	119	121	90	150	141	129
160	123	141	149	143	112	107	86	136	108
114	134	95	113	98	66	78	102	156	115
159	117	130	110	103	72	107	108	114	125
123	127	111	142	128	147	180	141	63	57
68	78	67							

hbc17

248	198	213	196	232	184	192	163	132	187
233	198	147	141	184	176	113	135	162	173
149	98	118	152	138	141	120	129	124	104
174	137	103	105	131	106	105	127	143	118
145	112	77	79	93	122	80	102	107	92
99	82	113	76	83	92	68	73	68	95
107	132	116	84	125	89	93	101	93	255

hbc18

170	169	186	208	213	200	115	135	207	227
232	199	287	254	176	503	476	331	242	279
241	199	268	242	175	175	144	145	157	98
160	94	138	113	108	119	117	118	110	109
105	110	134	147	143	130	113	151	102	125
95	74	85	68	78	76	79	88	89	76
89	107	113	102	106	70	110	87	86	108
119	97	85	126	122	91	104	101	128	102
118	150	129	111	86	74	100	148	88	119
188	131	107	113	101	115	94	109	127	118
125	120	133	106	131	75	128	80	99	88
52	87	100	112	139	136	157	96	125	121
117	143	119	111	101	194	149	137	147	170
150	169	161	176	164	148	167	149	87	114
136	112	190	129	103	164	145	143	212	130
180	216	168	156	139	170	158	227	303	257
155	187	147	147	118	204	138	120	154	166
146	101	114	103	159	170	146	211		

hbc19

90	122	106	83	103	145	87	110	150	111
101	74	61	76	106	83	92	139	109	110
98	123	112	119	121	99	97	106	94	100
118	116	90	72	81	100	86	91	86	102
82	125	91	76	89	87	114	106	160	87
97	84	69	56	98	162	115	164	112	142
104	113	108	131	95	106	173	170	165	162
153	254	235	232	224	241	119	119	166	196
185	185	224	188						

hbc20

168	144	120	126	144	124	104	126	220	159
150	154	162	134	136	87	148	159	132	102
93	109	113	123	106	115	111	96	136	115
76	69	75	69	71	78	91	78	96	114
75	67	60	97	77	106	83	77	91	63
84	64	55	64	67	77	78	105	114	132
132	79	124	112	99	117	98	103	124	99
89	96	81	100	113	105	93	100	58	67

hbc21

101	100	91	81	118	86	65	90	77	97
89	90	88	71	73	87	105	98	76	76
56	84	97	99	109	154	111	100	135	136
124	113	105	110	116	86	85	83	86	89
129	116	113	123	94	105	95	96	130	104
97	80	89	124	114	135	119	150	123	116
138	106	115	79	92	111	132	105	96	133
109	98	131	155	123	126	164	152	151	172
135	132	149	181	139	167	166	154	158	92
132	140	145	138	199	205	184	176	190	174
268	198	215	202	252	201	211	126	177	227
185	258	209	170	144	152	163	140	211	116
106	168	164	130	155	155	150	144	129	181
168	149	134	94	157	155	172	180	188	175
164	130	139	181	198	161	162	162	168	129
114	106	127	137	121	134	140	112	159	151
169	202	159	153	149	180	222	122	165	174
147	138	133	161	155	146	167	143	159	176
176	152	142	107	172	129	116	109	84	110
112	76	72	95	112	115	125	118	120	103
120	109	86	94	119	126	101	92	122	170
190	164	149	108	79	69				

hbc22

340	300	284	263	202	183	166	195	185	167
203	190	178	211	146	158	116	156	123	185
115	91	86	89	93	82	87	83	91	123
140	153	162	132	167	117	103	157	108	121
102	114	103	110	111	139	131	110	129	137
85	82	67	66	81	131	112	112	108	96
84	94	103	81	92	101	95	95	112	113
119	91	111	81	133	113	110	89	94	85
101	94	92	121	110	76	110	87	130	183
129	126	129	143	110	130	116	147	156	149
136	118	113	131	115	115	108	141	97	86
114	102	107	127	113	81	85	89	125	109
102	77	53	83	86	91	116	114	87	80
100	99	81	115	92	100	95	88	75	66
77	71	86	67	76	85	78	85	89	84
106	89	87	97	102	117	84	82	84	68
65	75	65	94	92	92	83	91	86	79
99	68	63	70	65	68	87	90	138	117
82	84	122	97	102	138	84	95	72	93
90	94	86	97	111	102	85	100	128	128
109	133	94	78	75	101	108	128	116	149
122	138	107	112						

hbc23

103	106	82	110	142	141	182	127	155	98
170	138	159	158	191	200	214	179	155	186
142	135	157	141	138	144	85	135	140	89
179	124	111	90	93	119	125	135	123	146
108	109	123	83	74	88	102	159	177	140
157	173	141	168	131	136	117	110	191	134
132	133	124	169	119	154	122	140	119	132
136	97	110	106	104	110	139	187	142	153
120	162	165	184	154	144	208	184	231	262
255	178	190	174	235					

hbc24

114	120	112	146	122	117	106	134	100	124
142	112	115	90	113	138	155	161	196	174
133	138	151	158	232	186	197	162	183	173
148	95	113	140	154	157	110	84	101	98
99	88	110	97	99	126	91	105	111	88
83	75	87	104	94	81	70	57	69	74
92	88	90	90	84	74	94	92	110	87
95	100	79	86	58	69	76	98	75	77
75	77	78	100	83	104	98	84	93	98
122	78	111	125	96	105	112	119	114	124
147	122	125	137	123	129	101	67	96	84
101	103	81	113	105	63	78	91	100	98
107	90	91	89	81	74	68	66	97	97
80	89	78	102	92	85	116	77	72	

hbc25

444	425	272	402	299	311	431	280	214	179
277	179	163	239	184	224	128	96	98	185
199	168	364	170	275	177	174	165	181	158
199	198	151	212	180	139	149	207	314	232
246	200	242	252	178	243	209	146	181	156
213	165	92	123	97	120	89	82	141	154
111	95	109	140	113	91	166	218	170	185
181	140	137	120	88					

hbc26

152	137	161	171	140	159	175	286	188	137
231	171	232	128	123	91	214	216	184	315
177	263	247	110	101	111	99	125	105	111
141	169	215	181	197	309	232	250	144	197
233	181	294	214	132	235	276	248	232	147
189	187	199	156	153	195	162	131	154	245
186	174	142	157	274	245	199	156	167	159
125	160	127	147	205	153	116	117	147	113
110	152	142	151	165					

hbc27

87	50	56	102	122	133	172	400	213	168
272	218	288	137	140	203	310	253	275	334
330	304	315	185	176	207	262	274	315	272
445	333	243	322	371	371	265	314	211	286
310	224	364	327	239	387	292	351	234	99
102	102	169	120	172	201	168	140	159	217
236	121	108	142	198	154	158	133	145	174
150	232	152	209						

hbc28

437	284	235	345	247	374	206	158	137	228
256	217	349	198	284	240	124	105	76	79
135	99	130	157	178	154	180	174	226	229
202	163	203	196	136	345	248	179	231	309
297	192	107	164	157	235	127			

hbc29

157	155	142	188	129	182	104	89	87	158
187	134	211	136	322	240	136	133	120	85
114	103	101	144	180	218	264	249	345	306
287	197	263	271	190	355	326	207	477	317
373	322	149	166	166	178	124	217	207	267
183	154	270	272	271	189	198	246	230	214
173	160	120	123	119	123	148	158	115	122
111	131								

hbc30

161	123	352	128	96	194	168	263	108	106
138	210	210	212	231	156	214	205	130	103
147	183	232	264	219	340	278	223	297	381
360	281	370	240	303	344	248	397	409	305
537	348	440	286	204	180	224			

hbc31

459	451	375	409	270	427	491	310	394	239
318	316	215	232	229	313	341	206	267	271
248	284	195	232	225	197	340	242	213	217
187	219	191	160	188	197	225	149	139	146
169	144	158	207	159	172	153	138	169	104
154	146	127	154	152	138	139	154	139	102
180	162	175	178	147	157	183	164		

hbc32

179	253	203	207	311	279	252	262	240	259
243	226	209	242	285	235	223	286	253	295
286	268	271	248	219	259	221	186	188	180
165	166	193	208	216	265	201	154	154	165
233	192	230	164	185	155	147	190	158	142
118	96	112	118	143	149	128	175	128	150
177	251	224	221	261	308	235	193	166	

hbc33

81	103	77	56	88	121	161	173	269	179
183	166	174	207	151	154	133	125	93	123
108	132	142	184	138	168	166	112	100	100
94	121	124	126	168	159	160	171	147	232
226	184	183	214	196	214	204	250	226	193
151	124	143	147	143	122	91	88	79	79
97	77	80	82	65	63	81	61	93	73
92	118	150	132	140	140	130	140	187	174
199	189	187	114	98	85	100	142	120	93
119	101	115	82	90	119	155	152	115	164
169	117	151	155	163	140	134	103	122	127
140	155	179	153	122	130	97	119	92	120
112	118	139	85	132	89	89	109	93	148
110	91	90	112	112					

hbc34

205	182	294	220	213	288	181	198	269	253
242	223	265	231	252	195	256	182	265	205
261	283	124	101	102	87	134	213	201	223
216	201	137	218	160	173	162	144	162	196
185	160	161	171	141	142	120	127	148	152
110	157	127	129	100	155	88	150	158	164
135	149	126	95	95	102	155	153	133	139
120	117	117	105	103	110	121	107	116	111
189	139	139	145	207	164	162	176	183	159
90	97	131	106	76	74	62	67	80	64
106	97	106	96	105	96	98	87	83	68
94	83	103	113	128	124	132	101	83	90
87	61	83	79	78	77	70	77	98	119
79	109	94	87	89	105	103	92	87	89
98	58	75	68	90	75	64	72	56	82
69	99	66	68	57	63	74	55	53	48
52	66	55	69	75	74	72	50	83	64
65	49	63	79	87	57	54	53	51	49
57	51	53	47	40	42	38	40	41	49
34	28	28	37						

hbc35

219	160	117	140	107	96	80	307	362	603
511	408	251	238	356	255	213	267	205	297
272	312	241	232	225	179	153	147	165	189
166	293	189	205	259	208	304	168	251	204
132	209	209	246	233	257	202	158	215	208
272	207	264	213	275	204	149	160	172	188
164	171								

hbc36

183	109	124	115	63	90	71	164	286	226
185	334	208	270	259	234	266	247	295	243
227	203	155	204	196	204	155	165	138	181
155	152	155	151	144	144	146	155	110	146
104	103	80	111	131	120	124	134	125	155
114	104	112	130	110	99	111	88	74	91
95	107	94	87	79	60	58	77	91	118
136	163	87	103	108	105	112	109	108	127
109	83	102	103	97	117	96	78	93	

hbc37

333	298	245	281	304	383	294	316	193	296
269	225	314	195	168	178	183	243	200	205
240	214	189	193	151	146	109	179	151	244
179	150	135	160	226	163	166	131	63	103
92	124	139	151	185	144	197	167	167	158
136	156	195	157	131	143	130	169	134	145

hbc38

307	175	225	232	193	250	189	383	304	210
161	205	169	202	195	189	214	161	188	268
198	187	236	247	249	233	240	96	105	169
160	215	281	332	101	72	76	95	79	61
50	85	89	83	69	76	112	129	156	142
181	81	113	190	226	157	156	156	122	99
86	67	119	106	102	116	86	98	99	82
89	104	104	126	124	126	107	64	57	57
87	72	91	124	166	127	90	116	99	91
110	83	101	63	41	56	59	75	74	74

hbc39

150	96	106	103	117	179	140	87	111	82
123	183	139	144	146	120	117	146	143	107
101	102	99	134	79	90	106	85	90	88
103	106	98	131	108	139	122	83	129	120
94	79	83	81	101	114	91	154	145	133
158	150	170	193	197	239	254	199	136	166
164	139	170	122	129	132	85	132	144	111
150	126	86	82	106	161	161	164	106	156
133	123	112	94	106	125	163	183	236	174
167	163	157	195	133	160	117	148	186	142
109	162	145	175	134	178	158	174	136	169
186	114	109	109	109	127	155	142	117	114
165	138	163	124	108	103	157	122	166	146
108	113	150	143	190	118	118	138	112	80
116	151	127	129	106	109	154	123	129	146
116	101	146	124	140	147	189	142	178	152
130	105	126	117	118	178	209	107	193	203
149	141	113	82	82	123	63	70	59	39
56	44	47	38	44	56	64	59	67	55
59	53	49							

hbc43

269	197	288	182	140	116	91	131	133	92
115	93	129	94	137	126	140	171	199	170
223	134	79	52	41	43	45	47	71	103
80	70	117	98	173	145	131	109	79	106
108	112	106	184	91	122	162	147	143	159
152	173	215	149	188	256	187	123		

hbc44

255	301	210	206	122	201	247	167	233	169
193	261	187	137	95	105	70	104	117	178
168	172	220	185	161	267	209	243	143	109
238	165	183	205	289	208	188	259	138	132
82	99	77	95	79	151	230	119	98	65
99	90	134	202	105	102	104	123		

hbc45

255	159	110	126	150	284	209	203	198	291
322	193	231	195	200	214	173	164	186	114
68	58	72	64	69	54	78	196	140	190
120	113	146	123	95	60	61	102	89	139
135	200	179	146	172	69	85	56	71	64
86	74	102	95	84	91	104	121	82	119
129	92	87	85	71	89	70	83	90	87
84	53	76	60	93	77	84	98		






ENGLISH HERITAGE RESEARCH DEPARTMENT

English Heritage undertakes and commissions research into the historic environment, and the issues that affect its condition and survival, in order to provide the understanding necessary for informed policy and decision making, for sustainable management, and to promote the widest access, appreciation and enjoyment of our heritage.

The Research Department provides English Heritage with this capacity in the fields of buildings history, archaeology, and landscape history. It brings together seven teams with complementary investigative and analytical skills to provide integrated research expertise across the range of the historic environment. These are:

* *Aerial Survey and Investigation*
* *Archaeological Projects (excavation)*
* *Archaeological Science*
* *Archaeological Survey and Investigation (landscape analysis)*
* *Architectural Investigation*
* *Imaging, Graphics and Survey (including measured and metric survey, and photography)*
* *Survey of London*

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

We make the results of our work available through the Research Department Report Series, and through journal publications and monographs. Our publication Research News, which appears three times a year, aims to keep our partners within and outside English Heritage up-to-date with our projects and activities. A full list of Research Department Reports, with abstracts and information on how to obtain copies, may be found on www.english-heritage.org.uk/researchreports

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

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