

Ancient Monuments Laboratory
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TREE-RING ANALYSIS OF TIMBERS
FROM HEADSTONE MANOR HOUSE,
PINNERS VIEW, HARROW, LONDON

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Summary

Ninety-nine samples from the Manor house were analysed by tree-ring dating. This analysis produced seven site chronologies, two of which date. The first dated site chronology consists of nine samples from a wide range of locations within the building. This site chronology has 107 rings that span the period AD 1439 to AD 1545. Interpretation of the sapwood, and the relative positions of the heartwood/sapwood boundaries on the dated samples, suggests that the timbers represented have an estimated felling date in the range AD 1554-84.

Given the wide range of locations of the samples in this site chronology it is perhaps not appropriate to infer a felling date range for timbers from specific locations nor a sequential development for the Manor house. Its dating does, however, suggest that a certain amount of work was undertaken at the site in the mid- to late-sixteenth century.

A second dated site chronology consists of eight samples, all from the open hall and cross-wing range of the Manor house. Interpretation of the sapwood, and the relative positions of the heartwood/sapwood boundaries on the dated samples in this second site chronology, suggests that the timbers represented have an estimated felling date in the range AD 1310-15.

A third, undated, site chronology contains seven samples and has 88 rings. The other four undated site chronologies consist of two samples each and range in length from 57 to 66 rings.

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Introduction

Headstone Manor (TQ 141897; Figs 1 and 2) is a grade I listed timber-framed aisled hall house with a cross-wing. Both parts are believed to be contemporary and to date from the fourteenth century. The Manor of Harrow was amongst the estates owned by the see of Canterbury, Archbishop John Stratford purchasing the surrounding land in AD 1344. Standing on a moated site adjacent to a tythe barn, the Manor is believed to have been partially demolished and then extended in the sixteenth century, these works affecting the great hall and high end in particular. Upon the Dissolution in AD 1546 the site was sold to Sir Edward North (later Lord North).

In AD 1631 the house was owned by the Rewse family who paneled the remains of the great hall and built an extension to the rear. Francis Rewse fought on the Royalist side in the Civil War, the debts incurred for this necessitating the sale of the house to William Williams in AD 1649. Williams built a substantial new wing, with cellars, pantry, and bedrooms. Subsequent owners built another wing in the AD 1770s, and gave the front a brick façade. The building was converted to a farmhouse in the seventeenth or eighteenth century and now serves partly as a local museum.

The Manor was the subject of a small programme of analysis by dendrochronology, undertaken by the Nottingham University Tree-ring Dating Laboratory in December 1995. This earlier tree-ring dating concentrated on sampling timbers from what is believed to be the earliest extant part of the present building, the open hall and cross-wing (Howard *et al* 1996).

The current programme of sampling and analysis by tree-ring dating was commissioned by English Heritage in conjunction with archaeological recording and analysis by David and Barbara Martin of the Institute of Archaeology, London. The purpose of the tree-ring analysis was to assist with the dating and the phasing of the building. The aim of the present programme of work is to would help inform the conservation process and assist in the drafting of repair proposals for the building. For the purposes of this report the samples obtained in AD 1995 were re-analysed in conjunction with those obtained under the current programme. More recently the tythe barn at Headstone Manor has also been analysed by dendrochronology (Howard *et al* forthcoming).

Establishing dates for the various parts of the Manor would provide information on the medieval development of this site, plus its post-medieval expansion during the fifteenth to seventeenth centuries. These changes are evidenced by structural alterations made to the Manor house during this time. It was hoped that it might be possible to link the changes at the house to the historical phases.

The Laboratory would like to take this opportunity to thank David and Barbara Martin for their help in interpreting the building, their assistance with sampling, and for providing drawings. The Laboratory would also like to thank Harrow Council for allowing sampling and in particular Jan Strode, David Whorlow, curators of the Centre, and the staff for their help, cooperation, and hospitality during sampling.

The building

A considerable amount of reconstruction has taken place at Headstone Manor, with a substantial number of timbers showing evidence of reuse. Given the suggested age of the site and the history of extension and alteration, Headstone Manor presents a complicated building sequence. A schematic outline plan of the site is provided in Figure 3. The original fourteenth-century high-end accommodation and part of the original hall towards the south end of the site have long since been demolished; only a portion of the original hall survives. Attached to the north side of what remains of the hall is the original cross-wing.

To the north of the cross-wing stand two additions, a west wing (running north – south) and an east wing (running east – west). It is believed that the west wing may be the earliest addition to the original fourteenth-century building, possibly having been built to replace the original kitchen in the mid-sixteenth century. The north gable shows that this phase was built with exposed close-studding and it may have been jettied along its west side. It is believed that some time later, probably in the mid-seventeenth century, the southern part of the west wing was rebuilt. It is thought probable, therefore, that the west wing contains timbers of two phases.

The east wing (also to the north of the cross-wing) is a two-and-a-half bay, two-storey structure with a tenoned purlin roof, probably of seventeenth-century date. This roof appears to be of a single phase of construction.

At the east end of the hall lies the “tower”, which contains timbers believed to represent four, or more, elements or phases of construction. At the lower level these timbers consist of phase I walls plus floor frames which may also be phase I, but may be phase II; for the purposes of sampling they are treated as two separate elements. Phase III of the tower consists of upper wall-frames and rafters associated with the heightening of this part of the building, possibly in the eighteenth century. The fourth phase here consists of a single roof truss to the south gable. It is believed that this was originally the north gable of a now missing structure formerly standing to the south of the tower. When this lost portion was demolished the roof truss was retained, becoming fossilized in the roof of the tower. The dating of all these phases is uncertain.

In addition to these phases the English Heritage brief requested samples from an enclosed outshut structure, attached to the south wall of the east wing. The basement walls here are of brick and flint of seventeenth-century character and they incorporate a seventeenth-century type brick mullion window. The roof itself is of the same tenoned purlin type as that over the north range. However, constructional details show that it must be later than the north range.

To the south side of this outshut is a timber-framed porch structure to the rear, or east end, of the hall cross-passage. Sampling of this area was requested to clarify the dating and phasing of the doorway.

Finally, samples were requested from the window, framing, and sub-structure of the west wall of the remains of the original hall.

Sampling

After discussion with David and Barbara Martin on the possible phasing of the Manor buildings and of the timbers available, and in conjunction with the brief provided by English Heritage, a total of ninety-nine core samples was obtained from the twelve phases/areas requested. Sampling was made particularly problematic by the quantity of reused timber. Each sample was given the code HED-M (for Headstone, site “M”) and numbered 01 – 99. Details of the samples are given in Table 1. In this table the timbers sampled are described by type (stud-post, tiebeam, etc), and identified by their unique timber-code number, where given, taken from the drawings provided.

The locations of the samples were also recorded on these drawings, reproduced here as Figures 4a-j. The sample numbers and their general locations are summarised below.

| Sampling location | Sample numbers | Sampling location | Sample numbers |
|---------------------------------------|----------------|------------------------|----------------|
| Tower wall frames – phase I | HED-M01 – 08 | Hall range – west wall | HED-M49 – 56 |
| Tower first-floor frames – phase I/II | HED-M09 – 16 | East-wing roof | HED-M57 – 64 |
| Tower roof – phase III | HED-M17 – 24 | Porch | HED-M65 – 72 |
| Tower – south gable truss | HED-M25 – 32 | Outshut roof | HED-M73 – 80 |
| West wing – north end | HED-M33 – 40 | Cross-wing | HED-M81 – 88 |
| West wing – south end | HED-M41 – 48 | Open hall | HED-M89 – 99 |

Analysis

Each of the ninety-nine samples was prepared by sanding and polishing, and the growth-ring widths measured; the data of these measurements are given at the end of the report. The growth-ring widths of all the samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix).

At a minimum *t*-value of 4.5 seven groups of samples formed, the relative off-set positions of the samples in each of these groups being illustrated in the bar diagrams of Figures 5 – 11. In these bar diagrams the samples are annotated to show its general location. It will be seen that some of the groups include samples from a wide range of locations within the building.

The growth-ring widths of the samples in each of the seven groups were combined at the indicated relative off-set positions to form site chronologies HEDMSQ01 – HEDMSQ07. Each of the seven site chronologies was then compared with a series of relevant reference chronologies for oak. This indicated dates for only two site chronologies, the *t*-values for these being given in Tables 2 and 3. This analysis is summarised below.

| Site chronology | Number of samples | Number of rings | Date span (where dated) |
|-----------------|-------------------|-----------------|-------------------------|
| HEDMSQ01 | 9 | 107 | AD 1439 – AD 1545 |
| HEDMSQ02 | 7 | 88 | Undated |
| HEDMSQ03 | 2 | 57 | Undated |
| HEDMSQ04 | 2 | 56 | Undated |
| HEDMSQ05 | 2 | 66 | Undated |
| HEDMSQ06 | 2 | 57 | Undated |
| HEDMSQ07 | 8 | 72 | AD 1234 – AD 1305 |

Each site chronology was compared with the other six and with the remaining ungrouped samples but there was no further, satisfactory, cross-matching. Each of the remaining ungrouped samples with more than 55 rings was then compared individually with a full range of relevant reference chronologies for oak but, again, there was no further satisfactory cross-matching.

Interpretation

The relative positions of the heartwood/sapwood boundaries on the samples within site chronology HEDMSQ01 lie within fairly narrow limits, having a sixteen year difference, 91 years relative on sample HED-M04 and 107 years relative on sample HED-M58 (see Fig 5). It is thus probable, that the timbers represented have the same, or at least a very similar, felling date. The provenance of the samples in site chronology HEDMSQ01 does vary, however, with the tower phase I, west wing (north end), west wing (south end), west wall, and the east-wing roof being represented.

The average last heartwood ring date of the samples in site chronology HEDMSQ01 is AD 1539. Applying the usual 95% confidence limit for the amount of sapwood on mature oaks from southern England of 15 – 45 rings would give the timbers represented an estimated felling date in the range AD 1554 – 84.

It is possible, though much less probable, that the timbers represented in site chronology HEDMSQ02 have the same (though unknown) felling date. This is because the relative positions of the heartwood/sapwood boundaries on the samples within site HEDMSQ02 chronology HEDMSQ02 have wide limits, ranging from 50, on sample HED-M18, to 88 on sample HED-M09, a difference of 38 years (see Fig 6).

Indeed, it appears more likely that two phases of felling are represented by this site chronology. Samples HED-M18, M41, and M59 may represent one phase of felling because the relative positions of their heartwood/sapwood boundaries are similar to each other. Samples HED-M09, M13, M45, and M46, which also have relative heartwood/sapwood boundaries similar to each other, may represent a different, later, phase of felling. The timbers sampled again have different provenances with the tower phases I and II, west wing (south end) and east-wing roof being represented. Given that the chronology itself is undated, it is not possible to calculate an estimated felling date range.

Only the eight samples in site chronology HEDMSQ07 appear to represent a single phase of timber felling from a distinct area of the Manor house, what may be the original open hall and cross-wing. The relative positions of the heartwood/sapwood boundaries on the eight samples lie within narrower limits, 43 years relative on sample HED-M86 and 61 years relative on sample HED-M90, a range of eighteen rings. The timbers in this area shows little obvious signs of reuse.

One of the samples in site chronology HEDMSQ07 (HED-M84) comes from a timber which had complete sapwood. Unfortunately about 5mm of sapwood was lost in coring, such a loss probably representing about 5 missing sapwood rings. Given that sample HED-M84 has a last measured sapwood ring date of AD 1305 this would suggest a felling date for the timber represented of *c* AD 1310, certainly no later than AD 1315. It is thought likely that this is the felling date for all the dated timbers from the open hall and cross-wing.

For the most part, the timbers represented by the samples in the other, undated, site chronologies appear to represent single fellings. This is because the relative positions of the heartwood/sapwood boundaries on the samples is very similar. It will be seen in Figure 7 for example, that the relative positions of the heartwood/sapwood boundaries on the two samples in site chronology HEDMSQ03 varies by only one year. The relative position of the two samples in site chronology HEDMSQ04, Figure 8, is the same. However, judging by their degree of cross-matching, it is likely that these pairs of samples represent single trees. Samples HED-M17 and M19, and HED-M26 and M27, for example, cross-match with each other with values in excess of $t=12.0$.

Conclusion

Analysis by dendrochronology has been able to provide only a rather crude estimate of the date of a modest number of samples. Some of the samples are from what is believed on stylistic and structural evidence to be the earliest extant portions of the manor house, the open hall and cross-wing. The dated timbers from this area suggest a felling date of AD 1310 – 15. This is generally in keeping with the fourteenth-century date expected for this part of the structure, though it is perhaps very slightly earlier than expected. Prior to tree-ring analysis of the hall and cross-wing it was generally assumed the original aisled hall was built *c* AD 1350. This was based on documents linking the site to the Archbishops of Canterbury, who owned it at this time. The tree-ring dates therefore have important implications for the early history of the site.

Other timbers from a wide ranges of locations are dated as being felled in the later-sixteenth century, having an estimated felling date range of AD 1554 – 84. Such samples are from a wide range of areas within the Manor house. This, and the fact that there is evidence of widespread reuse of timber, makes it difficult to reliably infer precise construction dates for the various phases or an evolutionary development. Nevertheless, the evidence for sixteenth-century fellings obtained by dendrochronology does support the conclusion that much reconstruction work took place around this time, based on fabric evidence.

Nearly all the samples have very short growth-ring sequences, many of them having only the minimum number of rings, 55, statistically acceptable. Below this number of rings less certainty can be placed on cross-matches because the amount of overlap between samples and between samples and reference chronologies becomes too small to be meaningful.

Several samples show wide and complacent growth rings with little variation in ring-width from year to year. The lack of a varied and distinct climatic signal in the growth rings may in part also account for the lack of cross-

matching and dating. Other samples show bands of very narrow or distorted rings and this too can make cross-matching and dating difficult. Despite these possible problems it was felt that attempting some analysis was worthwhile, given the importance of the site and the necessity of obtaining some understanding of its development.

This programme of analysis at Headstone Manor highlights the difficulties of providing reliable results and meaningful interpretation from a complex multi-phase building with quantities of reused timbers that produce poor samples. This work thus reinforces the argument for using a wide range of research and analytical methods at such sites.

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Table 1: Details of samples from Headstone Manor House, Headstone, Middlesex

| Sample number | Sample location | Total rings | *Sapwood rings | First measured ring date | Last heartwood ring date | Last measured ring date |
|------------------------------------|--------------------|-------------|----------------|--------------------------|--------------------------|-------------------------|
| Tower wall frames – phase I | | | | | | |
| HED-M01 | 1002 Stud | 55 | h/s | ----- | ----- | ----- |
| HED-M02 | 1003 Stud | 54 | h/s | ----- | ----- | ----- |
| HED-M03 | 1013 Brace | 59 | h/s | ----- | ----- | ----- |
| HED-M04 | 1019 Tiebeam | 71 | h/s | AD 1459 | AD 1529 | AD 1529 |
| HED-M05 | 1101 Sill beam | 67 | h/s | ----- | ----- | ----- |
| HED-M06 | 1106 Stud | 54 | h/s | ----- | ----- | ----- |
| HED-M07 | 1110 Stud | 52 | h/s | ----- | ----- | ----- |
| HED-M08 | 1120 Wall plate | 63 | h/s | ----- | ----- | ----- |
| Tower first-floor frames – phase I | | | | | | |
| HED-M09 | 1015 Sill beam | 59 | h/s | ----- | ----- | ----- |
| HED-M10 | 1016 Door jamb | 57 | h/s | ----- | ----- | ----- |
| HED-M11 | 1017 Top beam | 40 | h/s | ----- | ----- | ----- |
| HED-M12 | 1018 Door jamb | 37 | no h/s | ----- | ----- | ----- |
| HED-M13 | 1402 Floor joist | 56 | 3 | ----- | ----- | ----- |
| HED-M14 | 1404 Floor joist | 53 | h/s | ----- | ----- | ----- |
| HED-M15 | 1405 Floor joist | 57 | h/s | ----- | ----- | ----- |
| HED-M16 | 1406 Floor joist | 58 | h/s | ----- | ----- | ----- |
| Tower – phase II | | | | | | |
| HED-M17 | 1123 Brace | 66 | no h/s | ----- | ----- | ----- |
| HED-M18 | 1129 Stud | 54 | 10 | ----- | ----- | ----- |
| HED-M19 | 1131 Stud | 56 | no h/s | ----- | ----- | ----- |
| HED-M20 | 1132 Window sill | 48 | h/s | ----- | ----- | ----- |
| HED-M21 | 1611 Common rafter | 59 | h/s | ----- | ----- | ----- |
| HED-M22 | 1613 Common rafter | 56 | h/s | ----- | ----- | ----- |
| HED-M23 | 1614 Common rafter | 64 | h/s | ----- | ----- | ----- |
| HED-M24 | 1602 Common rafter | 69 | h/s | ----- | ----- | ----- |

Table 1: continued

| Sample number | Sample location | Total Rings | *Sapwood rings | First measured ring date | Last heartwood ring date | Last measured ring date |
|---------------------------|--|-------------|----------------|--------------------------|--------------------------|-------------------------|
| Tower – south gable truss | | | | | | |
| HED-M25 | 1041 Tiebeam | 56 | 9 | ----- | ----- | ----- |
| HED-M26 | 1051 East principal rafter | 54 | 8 | ----- | ----- | ----- |
| HED-M27 | 1052 West principal rafter | 57 | 8 | ----- | ----- | ----- |
| HED-M28 | 1053 East stud | 57 | 7 | ----- | ----- | ----- |
| HED-M29 | 1054 East queen brace | 54 | h/s | ----- | ----- | ----- |
| HED-M30 | 1055 East central stud | 55 | no h/s | ----- | ----- | ----- |
| HED-M31 | 1056 West central stud | 54 | no h/s | ----- | ----- | ----- |
| HED-M32 | 1057 West queen brace | 55 | h/s | ----- | ----- | ----- |
| West wing (north end) | | | | | | |
| HED-M33 | Collar | 71 | h/s | ----- | ----- | ----- |
| HED-M34 | East stud/queen post | 58 | no h/s | ----- | ----- | ----- |
| HED-M35 | East brace, purlin to principal rafter | 52 | h/s | AD 1492 | AD 1543 | AD 1543 |
| HED-M36 | Central upper stud | 68 | no h/s | ----- | ----- | ----- |
| HED-M37 | West stud/queen post | 56 | h/s | ----- | ----- | ----- |
| HED-M38 | West brace, purlin to principal rafter | 66 | h/s | AD 1475 | AD 1540 | AD 1540 |
| HED-M39 | Lower east central stud | 69 | no h/s | AD 1439 | ----- | AD 1507 |
| HED-M40 | Lower west central stud | 77 | no h/s | AD 1449 | ----- | AD 1525 |
| West wing (south end) | | | | | | |
| HED-M41 | East inner rafter | 75 | 20 | ----- | ----- | ----- |
| HED-M42 | Collar | 55 | h/s | ----- | ----- | ----- |
| HED-M43 | West brace to central frame/truss | 81 | h/s | AD 1462 | AD 1542 | AD 1542 |
| HED-M44 | East brace to central frame/truss | 54 | h/s | ----- | ----- | ----- |
| HED-M45 | West common rafter 8 from north end | 57 | h/s | ----- | ----- | ----- |
| HED-M46 | West common rafter 9 from north end | 54 | h/s | ----- | ----- | ----- |
| HED-M47 | West common rafter 12 from north end | 55 | h/s | ----- | ----- | ----- |
| HED-M48 | East common rafter 11 from north end | 56 | h/s | ----- | ----- | ----- |

Table 1: continued

| Sample number | Sample location | Total Rings | *Sapwood rings | First measured ring date | Last heartwood ring date | Last measured ring date |
|----------------|--|-------------|----------------|--------------------------|--------------------------|-------------------------|
| West wall | | | | | | |
| HED-M49 | 602 North window jamb | 50 | no h/s | ----- | ----- | ----- |
| HED-M50 | 607 Window head-beam | 57 | no h/s | ----- | ----- | ----- |
| HED-M51 | 614 South stud block | 55 | no h/s | ----- | ----- | ----- |
| HED-M52 | 615 Central stud block | 57 | no h/s | ----- | ----- | ----- |
| HED-M53 | 616 North stud block | 54 | no h/s | ----- | ----- | ----- |
| HED-M54 | 618 Wall plate | 46 | h/s | ----- | ----- | ----- |
| HED-M55 | 625 Wall stud | 57 | 14 | AD 1488 | AD 1530 | AD 1544 |
| HED-M56 | 626 Wall stud | 56 | h/s | ----- | ----- | ----- |
| East-wing roof | | | | | | |
| HED-M57 | South queen strut, east gable | 95 | h/s | AD 1441 | AD 1535 | AD 1535 |
| HED-M58 | North queen strut, east gable | 66 | h/s | AD 1480 | AD 1545 | AD 1545 |
| HED-M59 | North principal rafter, truss 2 (middle) | 81 | 23 | ----- | ----- | ----- |
| HED-M60 | South principal rafter, truss 2 | 79 | h/s | ----- | ----- | ----- |
| HED-M61 | South principal rafter, west truss | 55 | h/s | ----- | ----- | ----- |
| HED-M62 | Sill of east gable window | 54 | h/s | ----- | ----- | ----- |
| HED-M63 | North principal rafter, west truss | 55 | h/s | ----- | ----- | ----- |
| HED-M64 | North principal rafter, east gable | 58 | h/s | ----- | ----- | ----- |
| Porch | | | | | | |
| HED-M65 | 1801 South door-jamb | | h/s | ----- | ----- | ----- |
| HED-M66 | 1807 North door-jamb | | no h/s | ----- | ----- | ----- |
| HED-M67 | 1810 Short rail | | h/s | ----- | ----- | ----- |
| HED-M68 | 1811 Wall post | | no h/s | ----- | ----- | ----- |
| HED-M69 | 1813 Top rail | | no h/s | ----- | ----- | ----- |
| HED-M70 | 1815 Cross-rail | | h/s | ----- | ----- | ----- |
| HED-M71 | 1816 Cross-rail | | h/s | ----- | ----- | ----- |
| HED-M72 | 1803 North spandrell | | no h/s | ----- | ----- | ----- |

Table 1: continued

| Sample number | Sample location | Total rings | *Sapwood rings | First measured ring date | Last heartwood ring date | Last measured ring date |
|---------------|--|-------------|----------------|--------------------------|--------------------------|-------------------------|
| Outshut roof | | | | | | |
| HED-M73 | Brace, east wall | 57 | h/s | ----- | ----- | ----- |
| HED-M74 | West principal rafter | 58 | h/s | ----- | ----- | ----- |
| HED-M75 | Upper rafter 7 from east end | 56 | h/s | ----- | ----- | ----- |
| HED-M76 | Upper rafter 6 from east end | 56 | h/s | ----- | ----- | ----- |
| HED-M77 | Upper rafter 4 from east end | 57 | h/s | ----- | ----- | ----- |
| HED-M78 | Lower rafter 4 from east end | 54 | no h/s | ----- | ----- | ----- |
| HED-M79 | Upper rafter 2 from east end | 53 | h/s | ----- | ----- | ----- |
| HED-M80 | East principal rafter | 58 | no h/s | ----- | ----- | ----- |
| Cross-wing | | | | | | |
| HED-M81 | West brace, west crown-post to collar purlin | 59 | h/s | ----- | ----- | ----- |
| HED-M82 | West brace, east crown-post to collar purlin | 80 | 13 | ----- | ----- | ----- |
| HED-M83 | East brace, east crown-post to collar purlin | 47 | 9 | AD 1255 | AD 1292 | AD 1301 |
| HED-M84 | Collar, frame 2 from east | 41 | 20c | AD 1265 | AD 1285 | AD 1305 |
| HED-M85 | South common rafter, frame 13 from east | 63 | 8 | ----- | ----- | ----- |
| HED-M86 | South common rafter, frame 11 from east | 38 | h/s | AD 1239 | AD 1276 | AD 1276 |
| HED-M87 | South common rafter, frame 9 from east | 42 | 5 | AD 1254 | AD 1290 | AD 1295 |
| HED-M88 | South common rafter, frame 4 from east | 18 | 12C | ----- | ----- | ----- |

Table 1: continued

| Sample number | Sample location | Total Rings | *Sapwood Rings | First measured ring date | Last heartwood ring date | Last measured ring date |
|---------------|--|-------------|----------------|--------------------------|--------------------------|-------------------------|
| | Open hall | | | | | |
| HED-M89 | 004 Crown-post, south truss | 51 | h/s | AD 1239 | AD 1289 | AD 1289 |
| HED-M90 | 003 Tie-beam, south truss | 63 | 2 | AD 1234 | AD 1294 | AD 1296 |
| HED-M91 | West arcade plate | 29 | h/s | ----- | ----- | ----- |
| HED-M92 | East arcade plate | 60 | 3 | AD 1237 | AD 1293 | AD 1296 |
| HED-M93 | Window jamb in east wall of aisle | 33 | h/s | ----- | ----- | ----- |
| HED-M94 | Wall plate to east aisle | 39 | h/s | AD 1245 | AD 1283 | AD 1283 |
| HED-M95 | 001 South east corner post | 23 | h/s | ----- | ----- | ----- |
| HED-M96 | 002 South west corner post | 39 | no h/s | ----- | ----- | ----- |
| HED-M97 | Timber reused as tie-beam above wall plate, east aisle | 35 | 11 | ----- | ----- | ----- |
| HED-M98 | 102 Cross-beam at north end of open hall | 35 | h/s | ----- | ----- | ----- |
| HED-M99 | Stairway door jamb in service partition / cross-passage wall | 66 | h/s | ----- | ----- | ----- |

*h/s = the heartwood/sapwood boundary is the last ring on the sample

c = complete sapwood on timber, all or part lost in coring

C = complete sapwood is retained on sample, last measured ring date is felling date of timber

Table 2: Results of the cross-matching of site chronology HEDMSQ01 with relevant reference chronologies when first ring date is AD 1439 and last ring date is AD 1545

| Reference chronology | Span of chronology | t-value | |
|--------------------------------|--------------------|---------|-------------------------------------|
| East Midlands | AD 882 – 1981 | 5.6 | (Laxton and Litton 1988) |
| England | AD 401 – 1981 | 3.9 | (Baillie and Pilcher 1982 unpubl) |
| Southern England | AD 1083 – 1589 | 4.5 | (Bridge 1988) |
| Kent-88 | AD 1158 – 1540 | 5.6 | (Laxton and Litton 1989) |
| England London | AD 413 – 1728 | 7.2 | (Tyers and Groves 1999 unpubl) |
| MC10---H | AD 1386 – 1585 | 5.1 | (Fletcher 1978) |
| Sinai Park, Staffs | AD 1227 – 1750 | 4.7 | (Tyers 1997) |
| Chicksands Priory, Beds | AD 1200 – 1541 | 5.1 | (Howard <i>et al</i> 1998) |
| Lacock Abbey, Wilts | AD 1395 – 1546 | 6.0 | (Esling <i>et al</i> 1990) |
| 26 Westgate Street, Gloucester | AD 1399 – 1622 | 4.8 | (Howard <i>et al</i> forthcoming) |

Table 3: Results of the cross-matching of site chronology HEDMSQ07 with relevant reference chronologies when first ring date is AD 1234 and last ring date is AD 1305

| Reference chronology | Span of chronology | t-value | |
|------------------------|--------------------|---------|-------------------------------------|
| East Midlands | AD 882 – 1981 | 5.6 | (Laxton and Litton 1988) |
| England | AD 401 – 1981 | 5.7 | (Baillie and Pilcher 1982 unpubl) |
| Southern England | AD 1083 – 1589 | 4.6 | (Bridge 1988) |
| Kent-88 | AD 1158 – 1540 | 5.9 | (Laxton and Litton 1989) |
| Cubbington, Warwicks | AD 1170 – 1312 | 8.8 | (Howard <i>et al</i> 1988 unpubl) |
| Chichester Cathedral | AD 1173 – 1295 | 8.4 | (Howard <i>et al</i> 1992) |
| Thame Park House, Oxon | AD 1234 – 1319 | 6.3 | (Howard <i>et al</i> 1993) |
| Reading | AD 1160 – 1407 | 8.2 | (Groves <i>et al</i> 1997) |

Figure 1: Map to show general location of Headstone

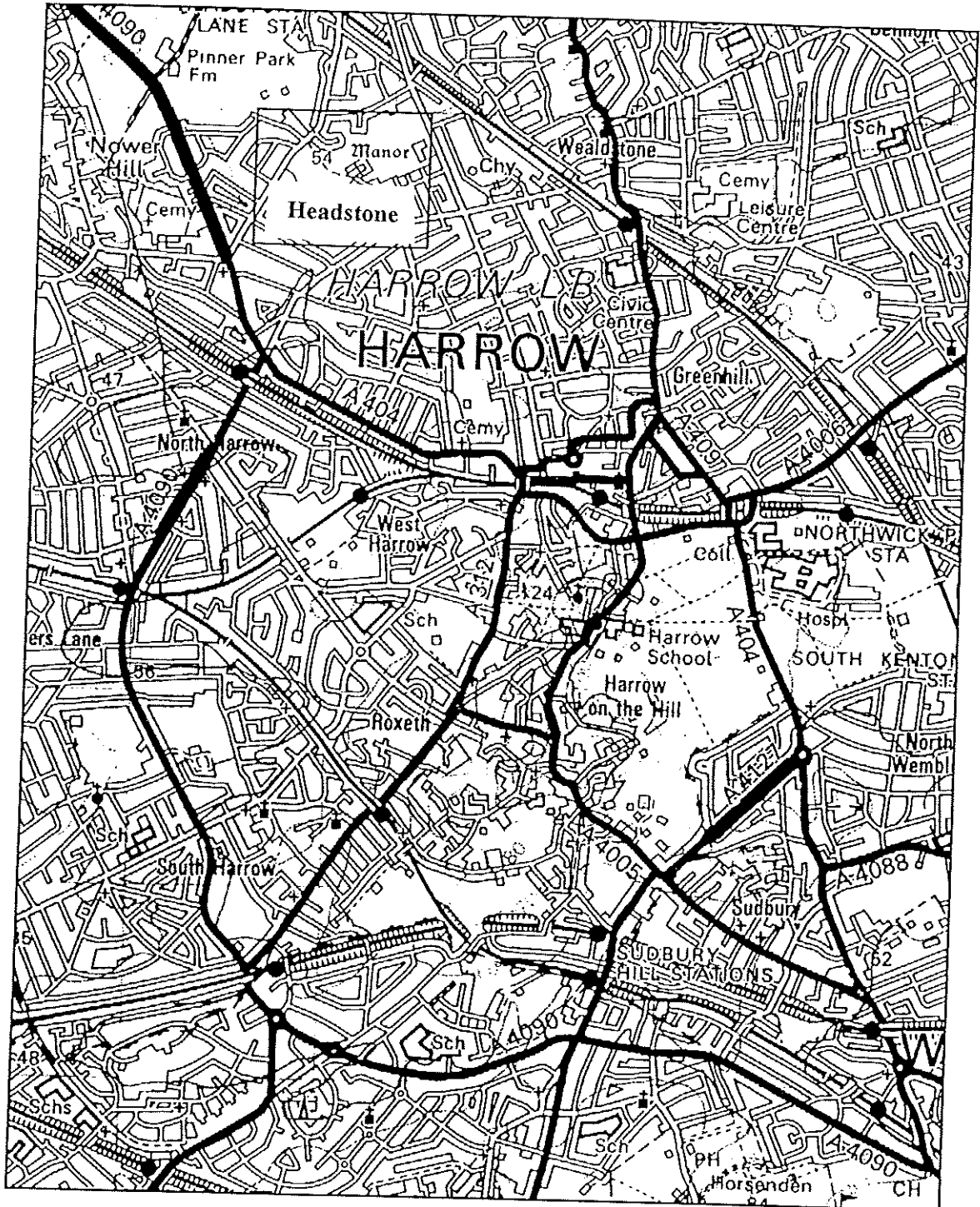


Figure 2: Map to show position of buildings at Headstone Manor

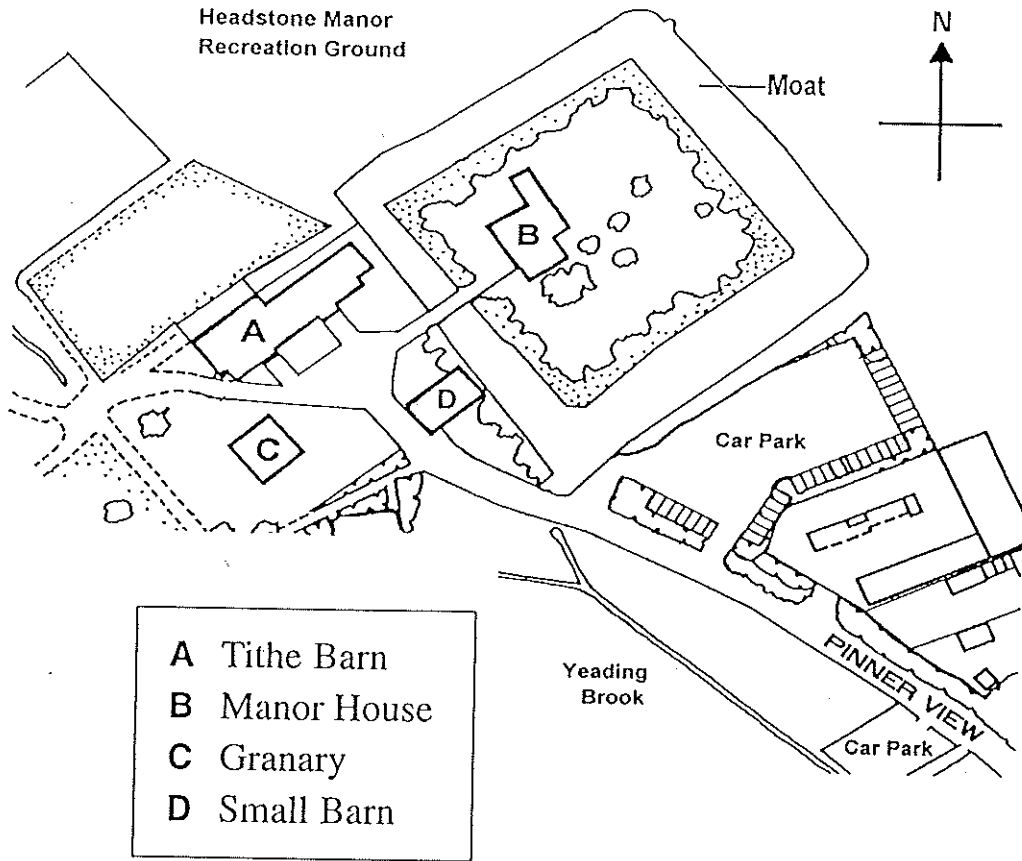


Figure 3: Schematic plan of Headstone Manor

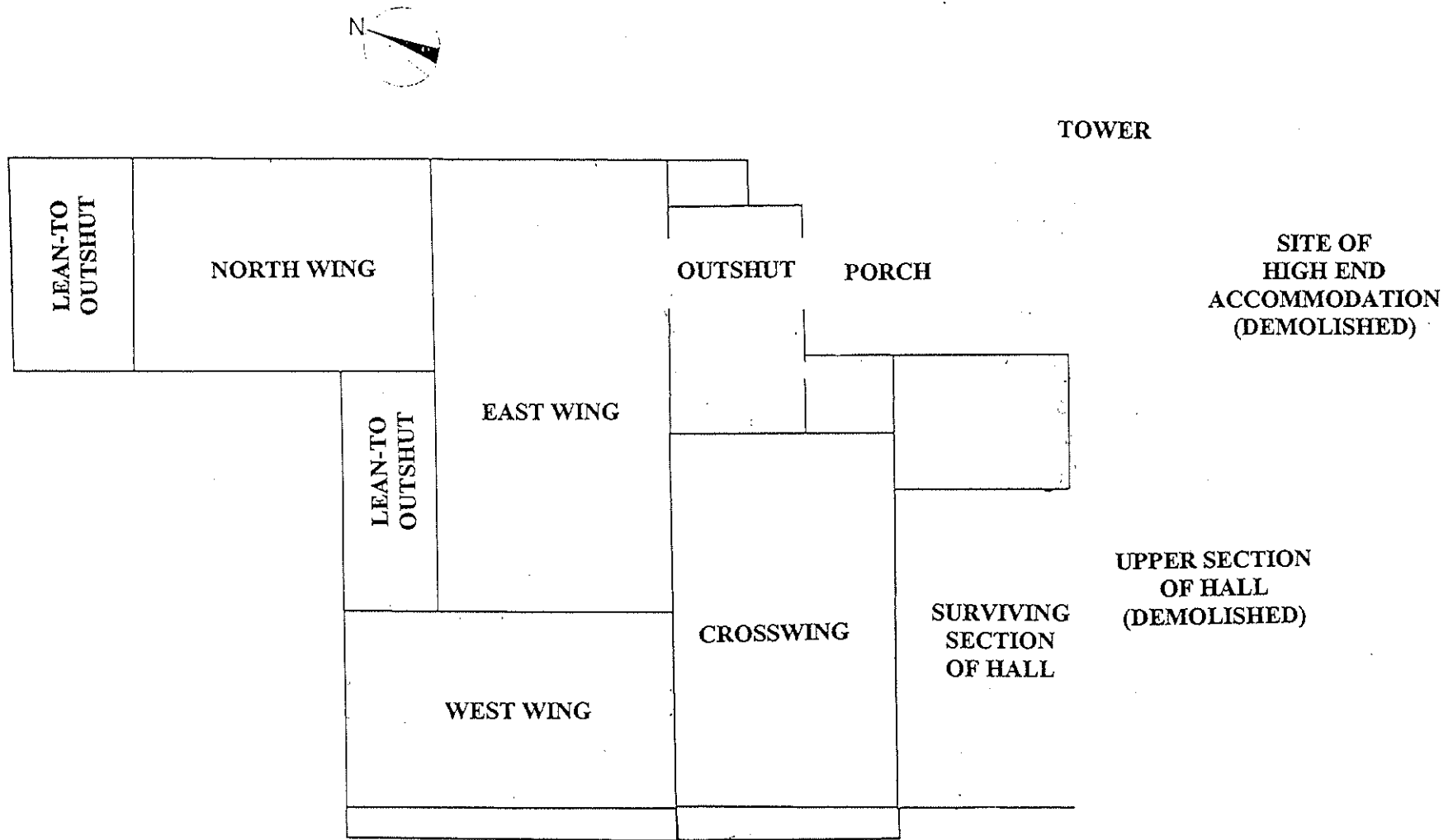


Figure 4a: South wall-frame of the tower (viewed from the south) to show timbers sampled
 (drawn by David and Barbara Martin)

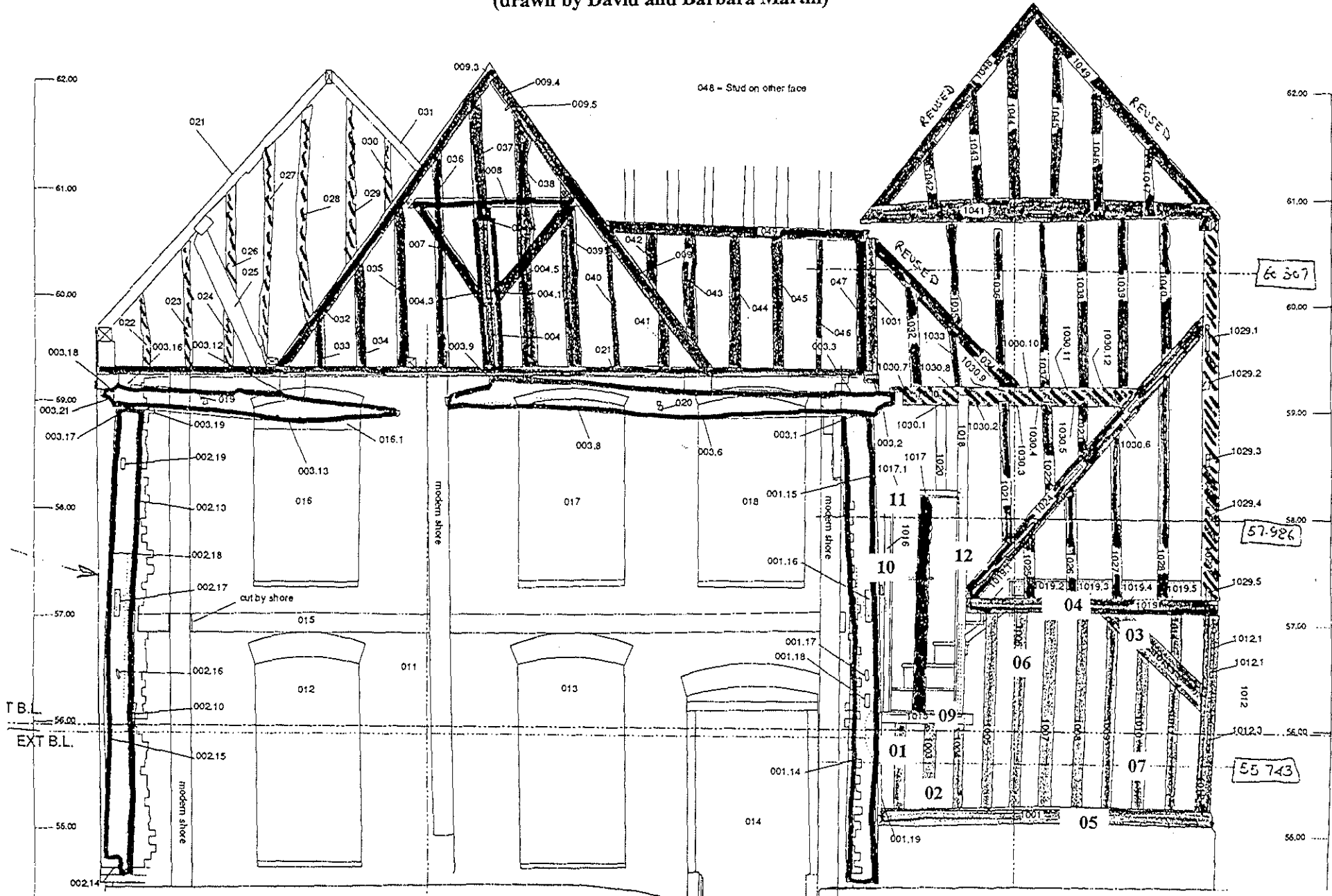


Figure 4b: Tower first-floor frame to show timbers sampled
(drawn by David and Barbara Martin)

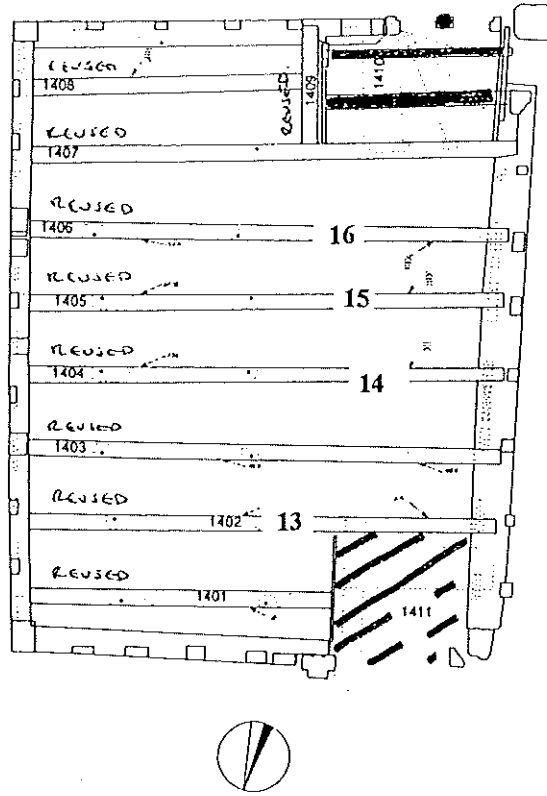


Figure 4c: East elevation of the tower (viewed from the east) to show timbers sampled
(drawn by David and Barbara Martin)

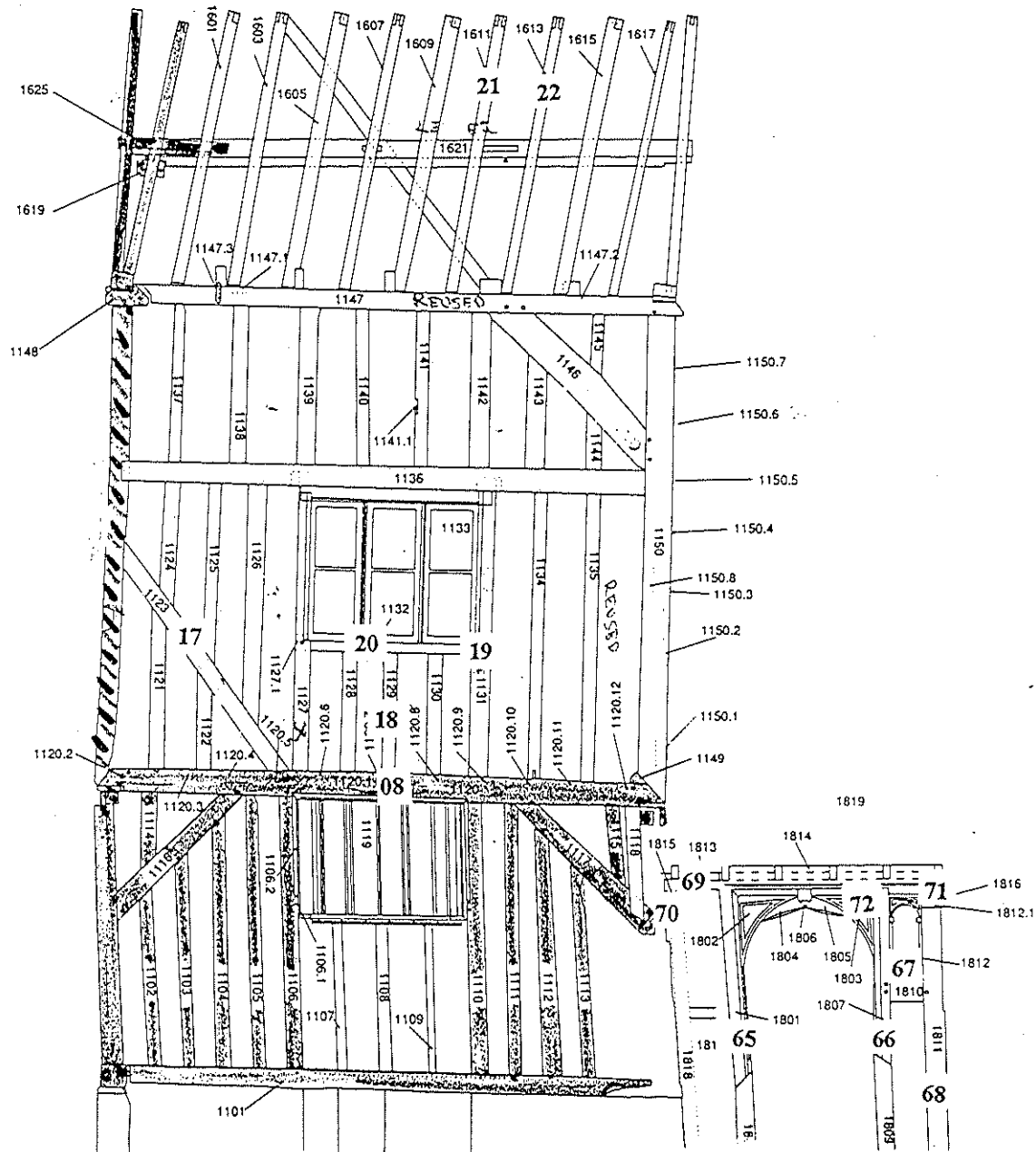


Figure 4d: West elevation of the roof of the tower (viewed from the east)
to show timbers sampled
(drawn by David and Barbara Martin)

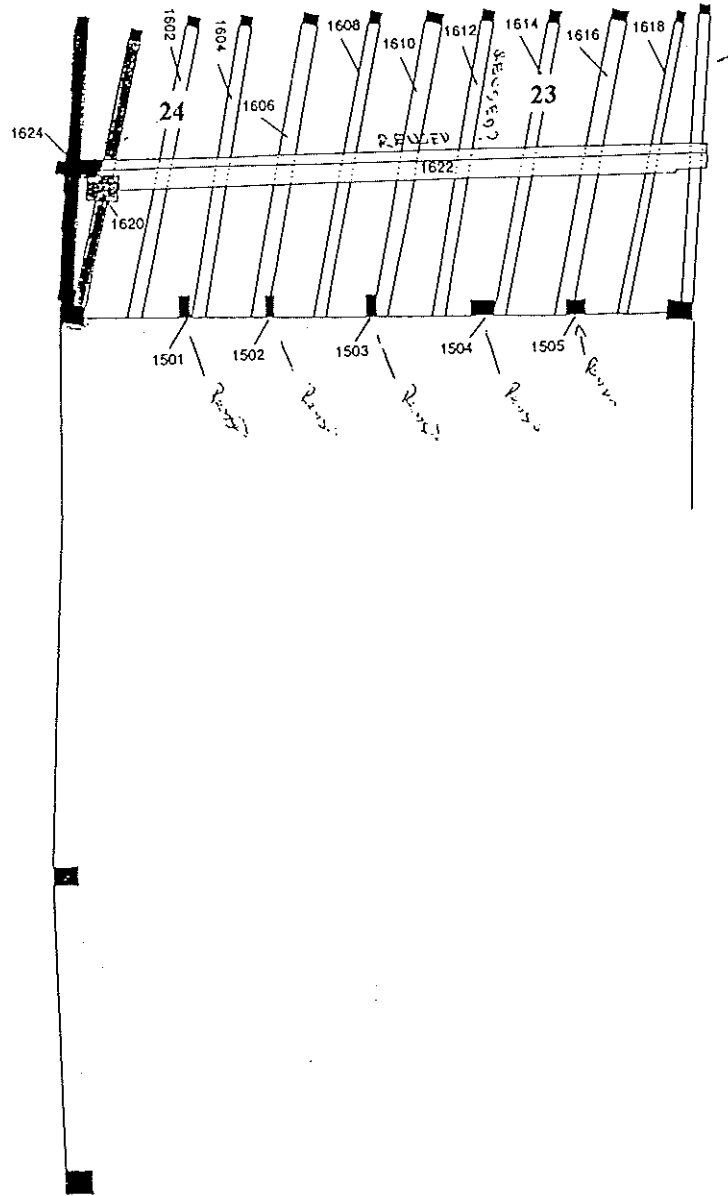


Figure 4e: Hall truss (viewed from the north) to show timbers sampled
(drawn by David and Barbara Martin)

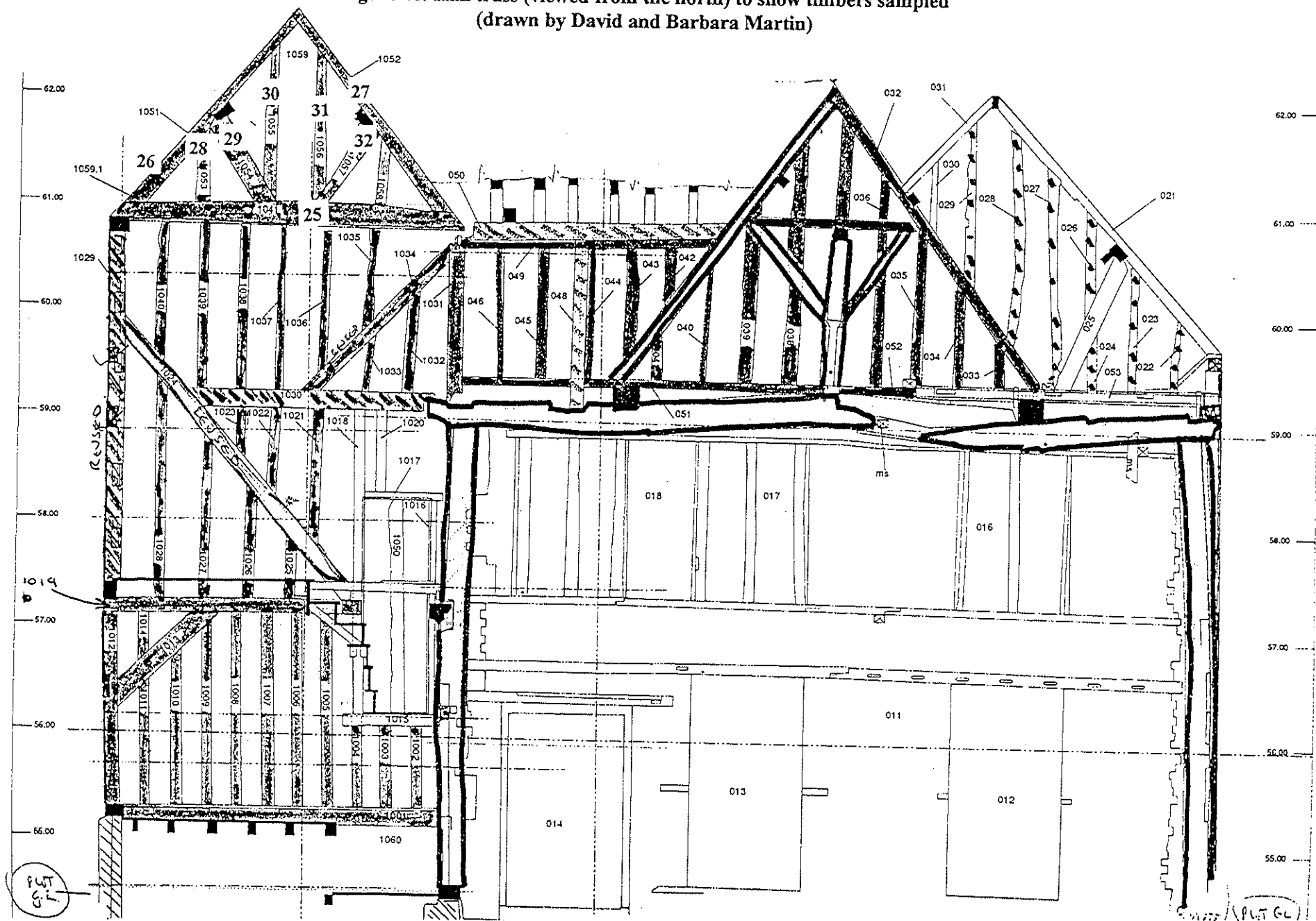


Figure 4f: West wall (viewed from the east) to show timbers sampled
(drawn by David and Barbara Martin)

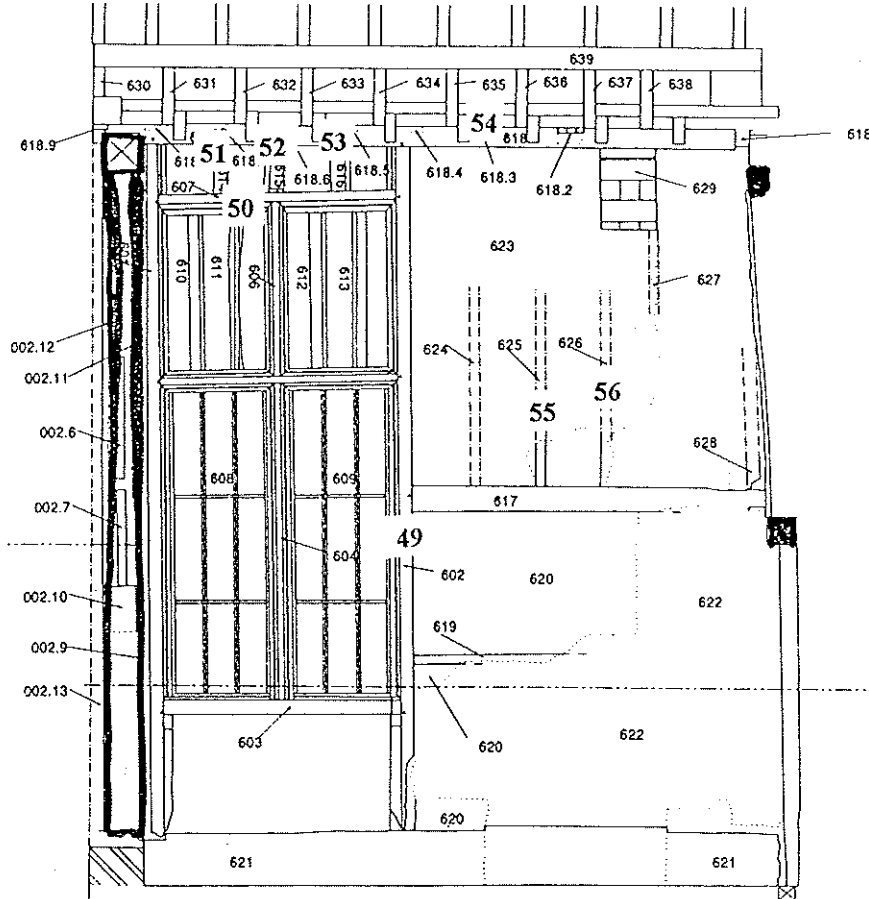


Figure 4g. Plan to show location of samples from the west wing roof
 (drawn by Richard Harris)

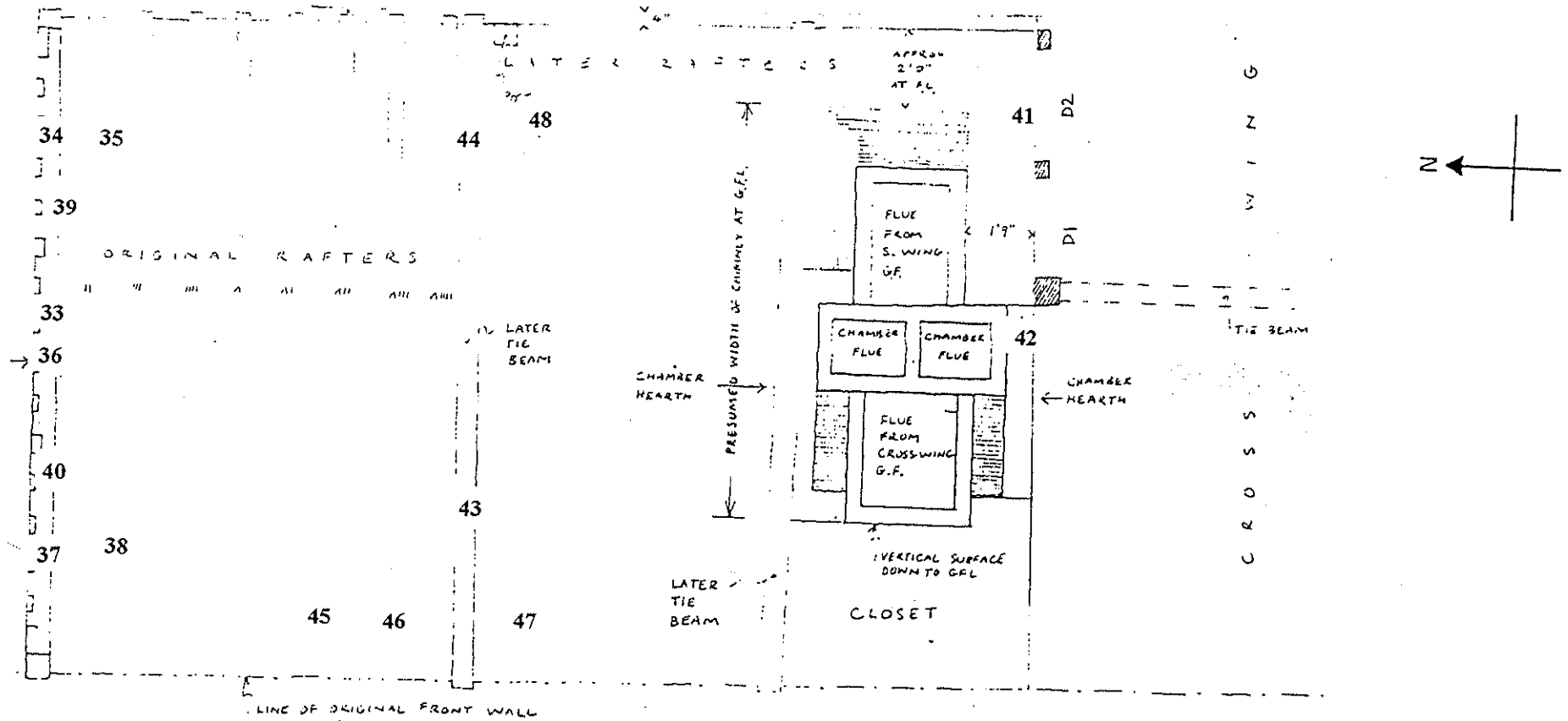


Figure 4h: Plan to show location of samples from the east wing roof
(drawn by Richard Harris)

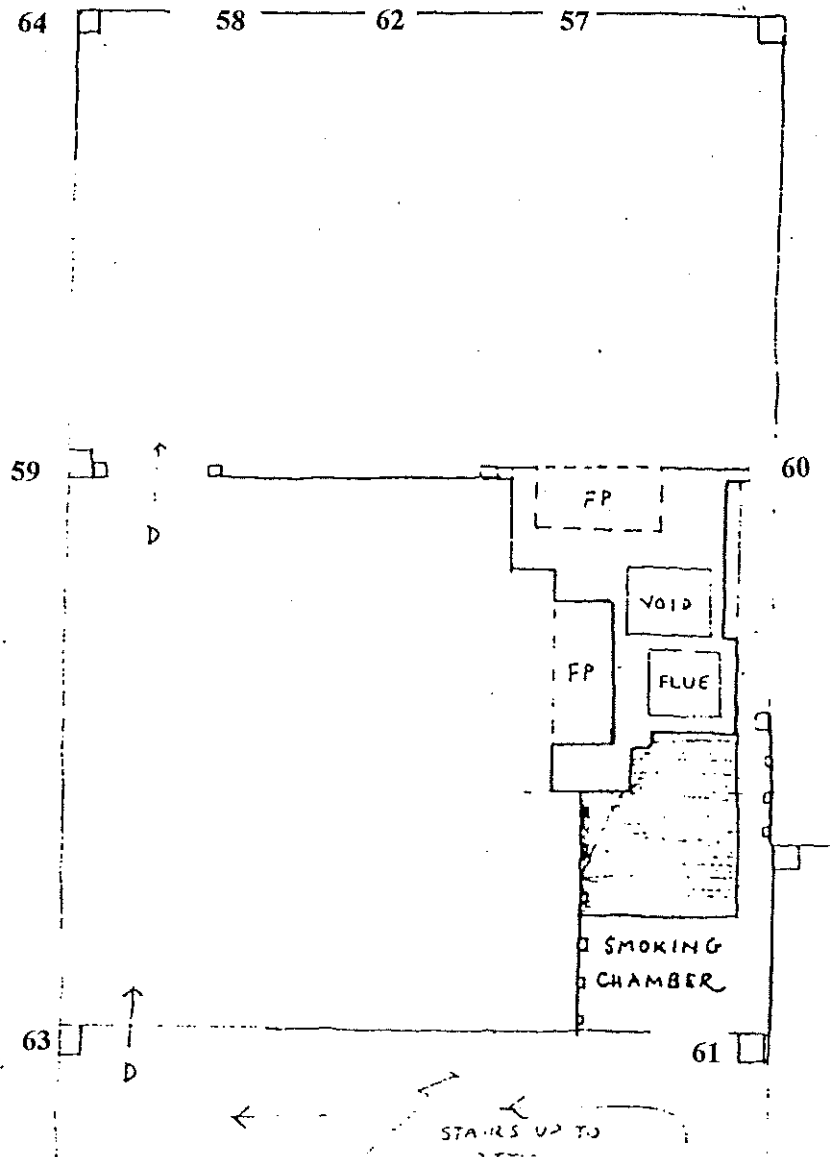


Figure 4i: Plan to show location of samples from the outshot roof
(drawn by Richard Harris)

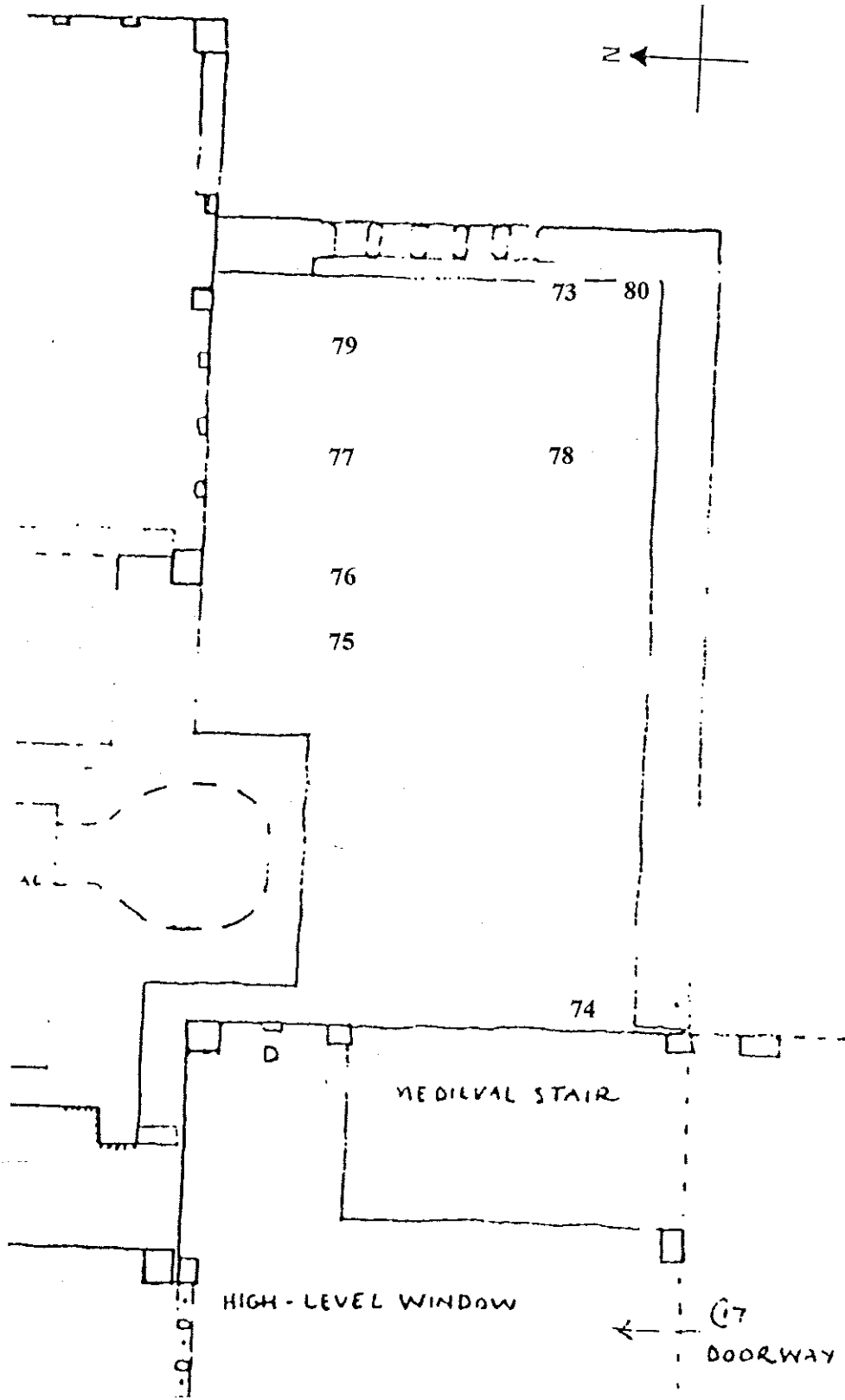


Figure 4j: Plan to show location of samples from the open hall and cross-wing
(drawn by Richard Harris)

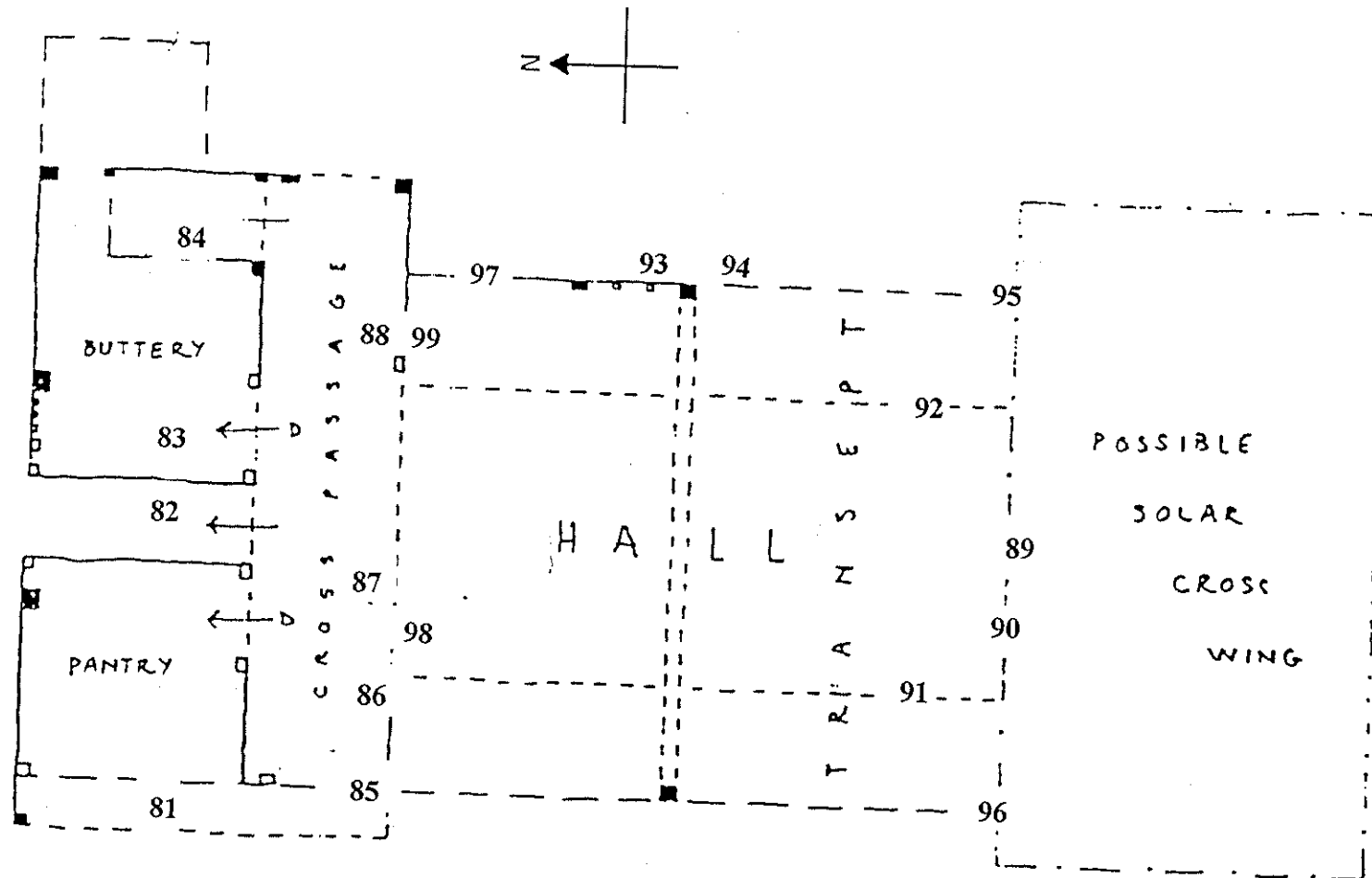


Figure 5: Bar diagram of samples in site chronology HEDMSQ01

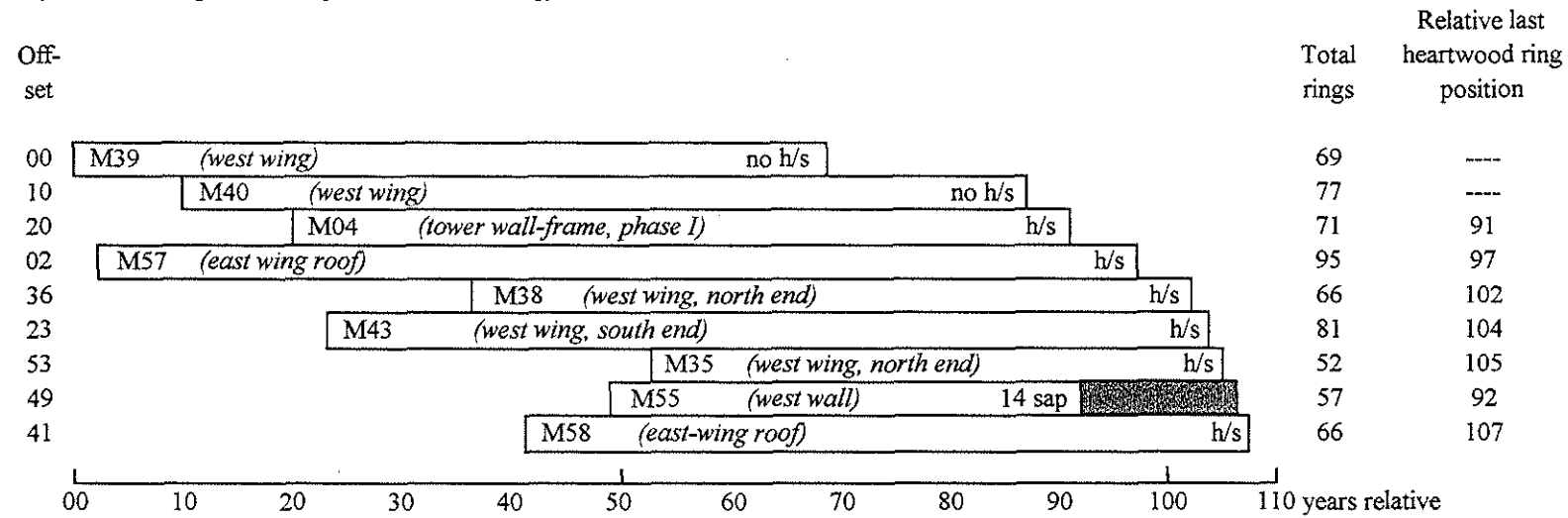


Figure 6: Bar diagram of samples in site chronology HEDMSQ02

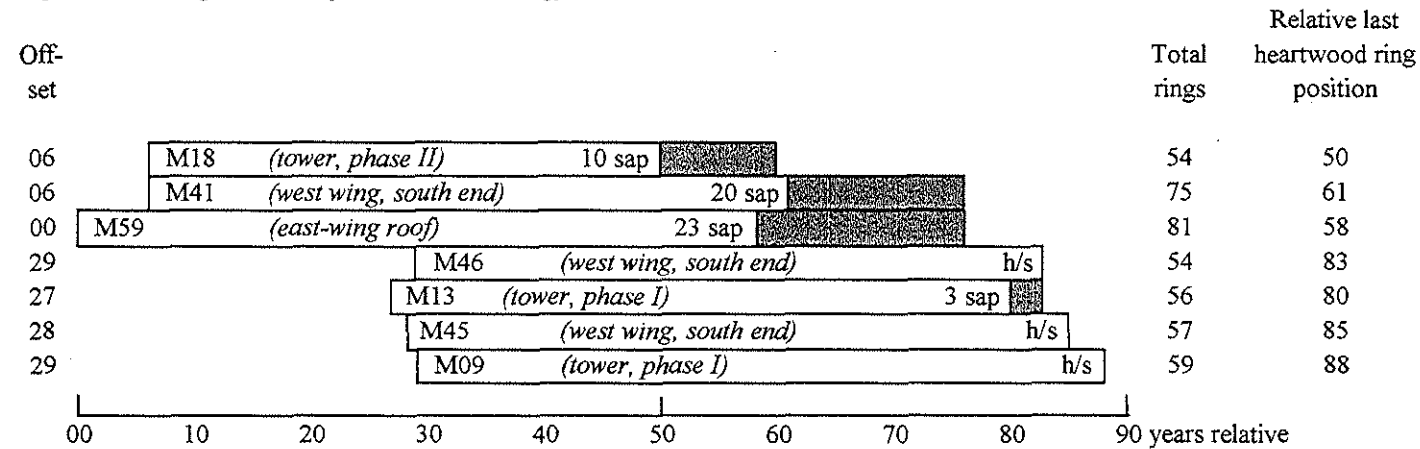


Figure 7: Bar diagram of samples in site chronology HEDMSQ03

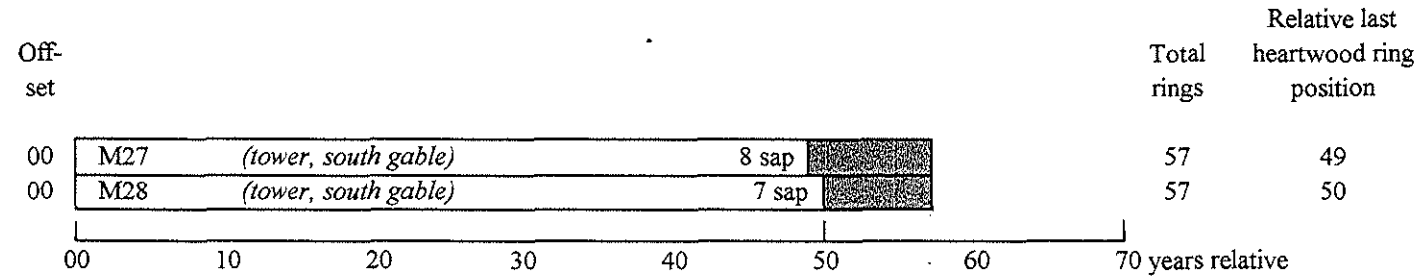


Figure 8: Bar diagram of samples in site chronology HEDMSQ04

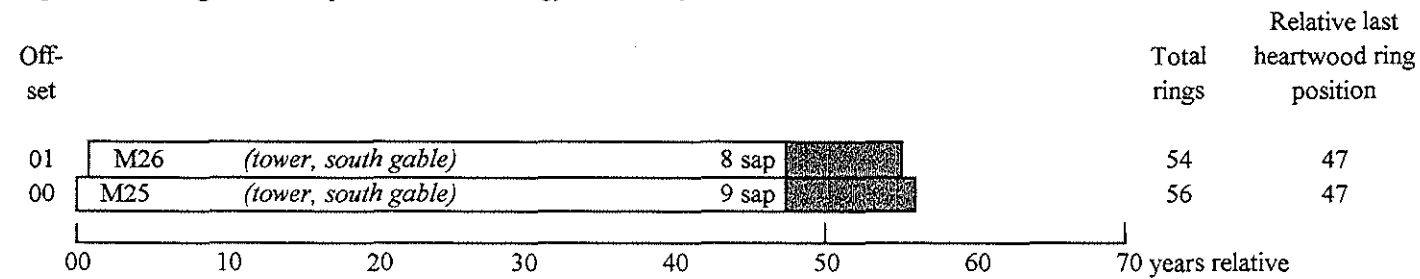


Figure 9: Bar diagram of samples in site chronology HEDMSQ05

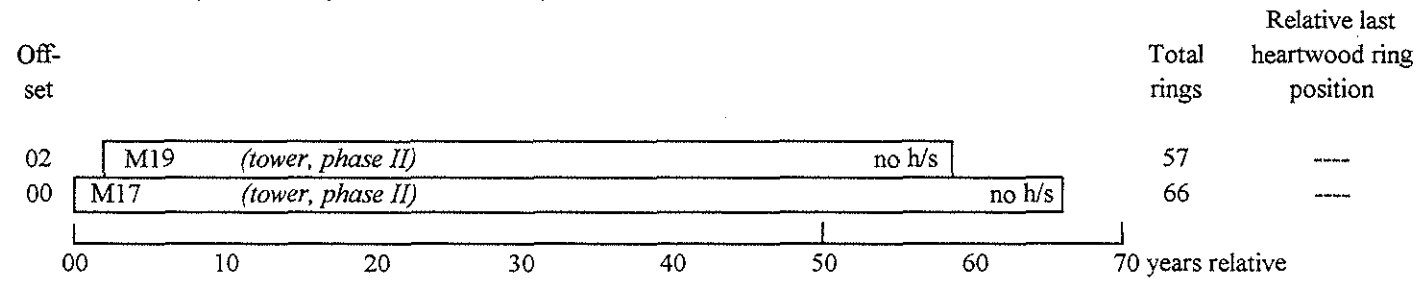


Figure 10: Bar diagram of samples in site chronology HEDMSQ06

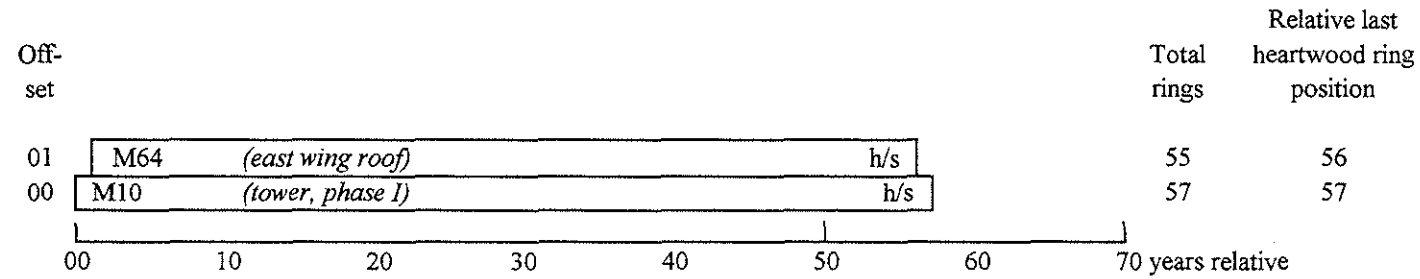
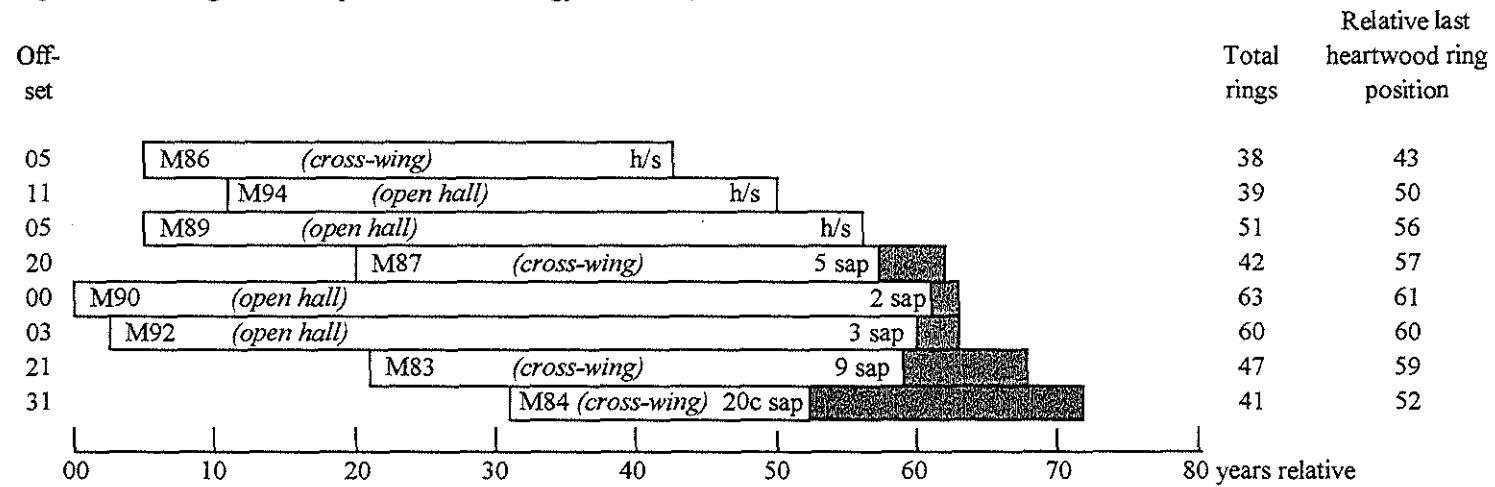


Figure 11: Bar diagram of samples in site chronology HEDMSQ07



White bars = heartwood rings, shaded area = sapwood rings
 h/s = heartwood/sapwood boundary is last ring on sample
 c = complete sapwood on timber, all or part lost in sampling

Data of measured samples - measurements in 0.01 mm units

HED-M01A 55

91 96 145 171 184 297 229 194 192 148 134 202 192 246 251 206 175 109 125 120
150 165 195 256 194 197 202 171 202 282 178 213 199 170 165 212 211 280 262 322
269 176 177 130 184 192 254 177 137 182 195 295 216 203 198

HED-M01B 55

85 103 146 178 200 293 227 194 193 137 137 204 192 253 255 218 171 103 122 124
156 168 198 258 177 189 206 172 200 272 193 219 205 159 166 197 212 285 281 323
250 186 168 149 165 177 281 255 151 178 187 286 227 192 193

HED-M02A 54

101 139 183 274 241 263 291 185 197 102 133 108 136 111 121 182 159 139 141 145
141 178 118 148 183 153 161 178 187 252 267 277 285 192 285 192 216 266 110 150
108 142 120 145 176 164 135 141 156 143 164 140 129 207

HED-M02B 54

108 149 173 288 256 247 301 193 212 128 111 109 128 99 156 158 152 133 148 142
130 168 120 155 195 148 160 182 162 252 263 265 304 181 267 202 213 218 97 136
118 120 126 130 170 159 138 155 149 137 181 135 137 195

HED-M03A 62

144 180 291 350 225 266 239 167 308 202 226 263 309 231 220 217 166 205 205 188
238 318 134 58 75 50 27 34 33 38 45 48 48 70 49 56 68 50 78 94
48 79 41 23 35 28 37 25 31 41 42 46 42 48 39 48 42 58 43 39
43 43

HED-M03B 59

123 194 314 344 240 310 211 182 297 169 222 315 309 219 223 204 186 198 200 202
249 312 120 64 76 50 34 32 27 35 40 37 61 50 61 53 70 55 73 83
61 74 40 27 36 24 39 39 45 42 44 46 44 46 45 57 38 43 48

HED-M04A 71

41 33 42 37 46 42 45 42 52 59 77 49 59 78 71 57 97 64 44 60
61 80 91 71 62 73 57 91 113 104 134 126 55 97 128 100 124 188 101 121
175 80 103 140 100 82 69 108 98 64 73 30 81 67 55 76 81 75 49 68
65 60 32 66 82 98 48 79 108 82 61

HED-M04B 71

38 34 36 48 44 33 52 43 50 59 66 54 68 69 70 64 83 67 47 63
60 71 93 68 69 68 67 88 109 107 146 131 63 92 126 104 131 193 115 121
175 93 118 127 105 81 73 94 87 66 82 36 82 63 54 73 84 72 45 63
68 50 44 63 77 89 55 84 114 77 57

HED-M05A 67

156 314 388 320 267 350 335 206 198 341 375 238 298 206 328 278 368 168 205 287
200 333 270 338 230 271 232 192 233 211 272 305 308 333 360 284 447 251 363 230
411 446 278 293 243 193 295 254 165 279 246 196 232 213 228 284 247 277 271 211
148 187 178 169 228 198 208

HED-M05B 67

169 310 390 337 318 305 339 205 198 335 374 260 321 201 295 275 337 184 193 276
187 350 258 360 210 248 234 200 231 210 269 317 287 351 332 292 463 258 363 218
409 421 279 275 231 193 262 239 162 265 233 199 243 194 210 309 239 263 281 229
176 166 177 181 224 191 209

HED-M06A 54

435 290 351 299 469 444 489 372 418 337 495 774 529 494 218 254 254 194 141 218
217 183 237 192 255 197 291 259 295 177 304 495 389 389 282 280 316 380 278 235
340 208 119 100 147 144 191 187 122 200 117 92 109 187

HED-M06B 54

444 277 374 292 481 427 497 382 400 340 491 756 537 488 226 259 242 204 151 202
199 198 238 183 243 196 278 278 265 191 306 470 387 378 298 264 307 374 295 234
350 204 125 109 143 184 172 168 153 234 105 92 129 158

HED-M07A 52

268 345 302 473 421 493 384 415 325 522 771 535 498 216 268 231 194 153 188 199
188 237 183 248 194 274 282 282 204 322 466 405 364 307 281 331 383 281 238 344
213 124 87 130 176 184 121 201 207 117 101 103

HED-M07B 52

271 339 311 466 422 499 358 409 337 499 800 524 492 216 277 253 213 185 180 201
181 250 195 238 201 281 253 252 198 298 475 401 378 305 269 351 377 296 233 343
205 110 107 107 166 188 176 206 215 114 107 122

HED-M08A 63

57 65 67 43 50 68 75 90 45 85 106 79 53 26 25 29 31 30 38 62
72 56 71 99 71 52 79 58 99 80 61 99 112 54 62 46 90 71 89 72
79 44 35 42 33 45 41 54 78 74 79 126 73 142 112 77 107 96 82 80
71 83 111

HED-M08B 63

54 67 66 51 44 67 82 91 47 80 108 74 55 30 25 24 27 39 43 50
63 51 73 101 76 39 89 64 96 73 62 98 114 48 71 49 87 63 89 67
66 47 33 41 40 43 39 56 77 68 84 125 73 141 105 81 103 94 109 65
64 71 137

HED-M09A 59

338 342 408 78 61 28 45 41 36 58 67 71 80 73 74 104 101 135 163 130
183 207 210 199 194 233 124 44 68 54 53 33 56 76 93 149 131 190 162 136
90 108 121 203 179 164 150 216 206 239 50 58 58 59 56 61 77 97 113

HED-M09B 59

402 362 425 87 56 28 45 35 40 59 64 72 78 65 81 104 105 151 135 121
194 190 225 206 192 204 136 57 51 49 51 49 48 76 99 146 152 193 140 146
94 117 128 196 197 157 159 200 211 245 37 51 60 58 65 59 80 92 120

HED-M10A 57

209 381 444 317 387 377 319 239 249 286 307 149 63 65 65 82 77 93 101 155
135 127 151 126 153 159 151 142 205 193 192 161 234 210 180 158 177 195 184 251
187 201 385 326 188 232 302 295 182 94 136 67 84 67 105 93 153

HED-M10B 57

221 373 463 299 327 377 345 202 244 286 272 136 81 61 74 81 78 94 97 157
138 129 141 139 134 176 139 146 176 200 195 158 244 217 179 155 315 201 234 231
150 233 359 328 177 255 270 294 87 96 105 71 85 77 87 99 151

HED-M11A 40

232 384 441 247 370 385 322 166 255 276 264 76 125 73 77 90 77 98 96 151
139 132 142 130 144 173 140 145 186 198 191 161 224 217 152 157 317 212 229 251

HED-M11B 40

235 394 446 329 401 367 322 233 233 282 281 144 74 71 65 82 76 108 94 150
143 137 144 133 138 177 146 122 193 202 193 168 228 216 173 166 316 199 254 263

HED-M12A 37

402 320 155 262 280 295 146 60 76 63 78 83 100 91 165 143 133 137 131 136
191 138 141 186 195 195 157 236 214 172 172 298 179 232 238 146 179

HED-M12B 37

369 318 252 231 275 288 170 66 84 71 78 74 105 93 153 146 124 152 121 157
175 135 145 155 189 195 162 234 220 173 159 325 188 233 225 163 186

HED-M13A 56

300 247 208 291 272 162 143 192 321 275 334 396 311 325 398 293 306 246 298 338
375 317 323 301 252 198 289 256 163 150 192 196 171 254 220 154 156 128 116 151
128 154 127 177 142 184 140 135 127 146 132 123 90 78 124 161

HED-M13B 56

295 244 202 280 259 168 138 166 286 308 301 392 279 333 371 330 293 263 300 328
374 337 313 297 256 182 290 260 161 144 170 203 177 258 229 159 158 136 103 146
125 160 134 185 136 164 153 128 125 128 127 109 103 82 125 155

HED-M14A 53

184 135 99 89 102 106 117 186 208 192 195 139 109 75 114 95 135 231 229 310
297 118 190 234 202 165 155 103 77 103 103 173 252 250 187 120 176 196 257 136
146 162 232 147 208 185 120 204 233 178 159 108 154

HED-M14B 53

180 131 105 84 104 101 95 183 217 183 196 139 98 79 111 94 132 248 225 311
291 115 196 220 182 158 157 103 65 103 116 187 251 242 168 141 179 196 236 148
145 168 223 157 185 171 123 206 259 173 169 135 170

HED-M15A 57

149 88 356 421 340 359 331 320 418 370 327 421 363 303 240 265 201 187 141 179
219 179 185 279 196 205 227 243 372 313 406 355 375 324 241 348 273 261 302 256
252 180 213 135 157 110 151 153 196 208 242 186 187 255 262 242 179

HED-M15B 57

162 82 275 473 288 349 336 308 453 352 332 415 366 300 232 256 207 173 133 183
208 202 167 288 187 219 218 244 322 317 440 357 358 304 260 348 275 258 309 243
245 174 213 151 145 112 149 156 194 197 252 183 182 248 271 229 175

HED-M16A 58

284 355 333 357 472 338 342 414 385 319 239 246 204 177 128 172 203 208 173 268
179 247 210 252 340 316 435 343 387 313 265 338 274 272 292 250 245 165 226 140
162 118 151 157 194 189 253 210 172 259 276 239 176 161 193 189 285 316

HED-M16B 58

286 367 318 311 423 361 332 410 359 310 239 254 199 181 135 187 211 199 169 269
186 218 236 234 340 313 421 357 365 311 247 350 276 261 307 246 235 176 225 114
157 128 130 160 196 211 240 192 176 244 266 246 184 154 195 198 260 333

HED-M17A 66

122 154 159 97 86 75 111 88 150 116 142 111 133 160 148 190 184 194 189 169
119 127 164 126 133 151 124 118 149 134 109 159 154 225 244 275 186 127 138 146
206 180 210 162 150 166 193 187 186 215 154 121 126 133 143 142 159 136 142 135
121 125 131 143 123 147

HED-M17B 66

130 162 152 103 80 85 110 92 146 115 126 159 108 152 155 188 185 202 180 162
113 134 169 125 136 147 123 107 160 126 122 166 165 234 227 309 188 149 144 137
210 168 214 153 154 176 187 188 195 214 156 120 108 139 141 145 167 130 149 140
117 134 127 125 129 175

HED-M18A 54

465 340 460 520 430 387 388 327 111 52 72 56 103 123 106 142 109 133 128 148
148 155 158 117 142 206 142 55 46 46 62 77 62 54 40 27 72 84 92 82
122 99 122 106 138 142 171 200 191 180 213 210 199 231

HED-M18B 54

379 376 463 491 450 365 391 355 68 88 64 68 94 119 103 140 114 138 127 138
162 155 152 124 134 218 165 58 46 42 69 81 56 53 43 29 68 85 90 78
125 96 121 106 137 135 207 179 187 188 205 228 198 249

HED-M19A 56

100 83 73 113 83 145 117 141 133 125 139 140 177 190 195 194 170 129 123 164
133 137 145 128 110 164 114 131 164 152 221 224 277 188 148 137 139 200 161 241
170 161 172 182 182 189 217 161 122 113 149 145 159 165 130 143

HED-M19B 55

100 97 79 114 80 157 114 135 147 131 126 137 189 190 195 193 168 120 128 170
128 154 129 121 122 145 132 135 168 150 234 239 268 187 135 120 164 188 182 205
164 152 167 185 194 198 192 166 137 109 135 147 154 160 130

HED-M20A 48

197 177 63 38 90 85 103 77 94 61 67 74 128 130 126 145 130 154 135 144
159 176 175 202 191 183 148 145 199 172 70 45 86 81 103 81 90 48 64 77
131 136 123 134 133 160 130 158

HED-M20B 48

209 165 59 48 84 96 99 71 92 61 56 79 130 123 141 126 128 155 121 156
171 175 176 187 193 181 154 140 201 169 72 48 79 106 106 96 93 39 62 88
137 124 132 130 129 148 134 154

HED-M21A 59

190 178 238 268 122 58 56 60 50 56 51 93 100 88 87 313 363 418 233 270
154 217 255 230 338 168 208 226 140 164 154 206 224 272 132 62 54 58 48 60
46 82 100 84 60 118 104 130 82 72 135 130 96 179 148 190 264 277 203

HED-M21B 59

209 200 247 276 130 57 54 64 63 58 43 105 101 90 89 323 359 381 237 285
167 215 262 234 334 170 210 224 136 173 170 198 235 267 139 59 58 50 51 64
45 89 98 84 66 103 105 133 81 72 134 133 102 180 141 180 264 253 207

HED-M22A 56

197 316 178 152 284 268 266 200 311 168 152 297 295 243 240 231 414 359 433 237
203 162 161 258 226 340 165 201 216 134 140 177 141 184 170 110 36 41 44 36
39 87 59 88 68 93 107 116 120 90 159 153 118 239 167 227

HED-M22B 56

195 322 183 151 279 308 245 218 308 188 150 263 324 254 258 238 411 358 420 234
215 145 156 247 254 325 178 207 207 126 130 179 135 210 151 108 55 45 28 43
82 79 73 86 64 94 113 113 129 79 164 159 109 240 156 227

HED-M23A 64

289 141 113 147 130 185 116 135 139 98 86 144 162 182 182 112 38 31 49 51
45 53 75 99 85 82 116 121 170 147 103 147 154 93 179 164 220 317 199 85
31 26 26 42 59 60 69 86 85 145 72 90 67 67 76 74 73 69 61 85
75 83 83 88

HED-M23B 64

216 131 121 153 127 198 114 138 148 97 87 134 169 188 187 105 41 34 47 45
50 47 81 98 82 80 118 122 175 144 97 158 154 112 170 173 225 307 209 96
31 17 22 52 57 61 75 81 87 142 78 82 70 76 70 69 80 61 64 83
78 79 87 91

HED-M24A 69

353 198 156 106 110 85 87 64 52 68 65 92 101 163 127 110 163 136 101 122
98 150 180 148 152 118 92 95 109 126 144 151 161 172 129 172 110 132 130 142
184 163 178 228 217 291 315 209 167 153 174 218 263 189 277 223 185 232 206 279
295 256 183 156 169 214 157 176 217

HED-M24B 69

321 219 155 114 107 96 94 56 53 64 62 101 106 164 111 134 168 137 107 110
97 148 185 152 141 107 100 93 105 132 135 165 166 157 153 165 109 137 120 148
185 165 198 220 214 308 318 197 160 160 174 230 252 206 247 249 156 232 214 272
279 251 181 154 175 179 166 166 242

HED-M25A 56

443 170 264 176 304 318 571 593 418 385 315 335 278 318 423 346 363 269 251 205
199 194 219 237 215 163 178 185 239 218 259 210 346 280 371 438 513 509 484 376
348 299 342 372 261 232 157 184 174 201 190 206 199 247 263 282

HED-M25B 56

402 191 260 200 277 321 513 596 436 397 335 345 265 339 420 350 365 289 267 196
209 190 221 233 219 163 175 187 238 230 245 217 332 286 368 429 521 509 461 410
333 317 326 378 271 228 165 178 186 182 215 221 188 258 254 279

HED-M26A 54

177 254 187 273 311 546 727 506 384 332 310 231 359 417 332 344 278 268 195 205
178 232 238 187 183 177 185 248 229 264 225 317 295 370 442 524 490 473 375 341
308 336 373 249 247 147 171 184 193 209 206 186 265 267

HED-M26B 54

197 246 180 289 321 587 610 462 390 369 288 221 386 416 343 334 267 254 191 217
177 227 225 222 151 175 181 253 211 254 217 320 293 372 444 494 520 474 396 332
321 335 360 272 231 161 183 195 186 191 228 183 262 277

HED-M27A 57

271 170 176 103 276 345 321 294 408 346 328 365 337 589 480 572 518 607 507 476
636 504 593 569 520 441 431 398 426 315 344 418 416 502 525 558 532 589 483 482
560 489 499 563 574 361 378 311 334 413 319 384 329 304 125 171 156

HED-M27B 57

251 190 172 118 265 304 371 255 411 338 326 376 345 598 478 572 487 564 477 471
630 552 555 546 468 430 428 388 412 336 356 398 420 493 503 583 534 605 457 488
556 484 523 527 586 362 385 306 328 413 297 333 342 322 116 167 169

HED-M28A 57

268 174 187 114 261 312 377 272 388 328 344 381 340 591 481 590 499 611 505 472
633 541 559 595 495 455 445 406 388 315 362 375 434 474 502 581 541 604 468 483
553 472 547 553 561 361 395 294 325 416 316 349 294 324 134 165 150

HED-M28B 57

284 184 186 112 265 295 375 291 386 343 304 384 342 595 479 596 463 596 515 474
640 506 577 577 502 457 413 412 409 311 356 387 405 493 548 555 572 579 457 488
541 482 529 556 567 364 376 298 337 411 317 371 333 289 126 165 172

HED-M29A 54

331 359 390 424 497 510 577 502 587 496 437 501 519 568 553 599 497 468 556 492
587 497 606 484 480 572 476 512 536 572 364 389 300 343 409 306 378 312 309 130
59 157 163 286 400 366 311 340 295 318 132 169 257 288

HED-M29B 54

316 357 406 417 478 513 580 535 609 466 425 481 523 568 573 604 462 477 561 474
567 504 612 467 481 582 484 518 549 580 358 387 294 342 396 307 356 289 333 132
65 167 278 272 409 307 358 287 336 320 150 155 267 234

HED-M30A 55

90 84 95 81 74 84 77 63 62 52 83 103 87 64 95 90 82 115 142 137
130 115 129 156 142 195 141 118 90 113 112 96 83 90 121 230 176 171 101 153
223 200 138 95 106 90 122 98 149 129 276 182 141 307 288

HED-M30B 55

80 102 87 99 57 81 78 71 64 59 82 93 92 57 105 84 92 114 127 142
126 118 136 155 147 173 165 113 98 98 130 75 86 86 120 236 178 180 110 156
190 222 119 90 80 110 93 114 163 97 303 218 135 284 293

HED-M31A 54

218 131 151 198 126 143 169 216 213 214 179 193 310 270 221 218 154 133 192 167
121 137 108 155 124 112 115 186 201 233 180 187 210 182 177 179 166 201 277 211
207 166 193 187 246 218 266 258 351 410 391 395 362 367

HED-M31B 54

206 129 145 180 152 128 179 205 215 197 177 200 341 277 217 234 124 130 188 167
121 122 117 156 111 113 118 183 215 221 172 187 213 186 182 187 157 201 291 197
192 163 202 185 267 214 265 260 343 396 390 414 372 345

HED-M32A 55

70 42 79 73 62 66 64 64 86 83 61 65 60 72 78 121 123 137 152 96
84 89 82 95 66 97 77 68 66 59 73 95 88 66 91 95 80 117 125 143
127 83 106 86 65 85 97 86 112 138 135 134 120 137 152

HED-M32B 55

87 80 65 68 64 70 68 86 71 128 103 138 171 94 81 62 61 65 77 79
122 123 134 152 105 78 81 93 92 73 92 82 63 64 56 88 79 100 76 95
84 93 96 137 130 134 84 96 96 74 94 87 83 122 132

HED-M33A 71

206 154 114 137 100 216 175 108 182 152 261 214 184 140 92 101 177 132 182 123
115 72 82 78 82 98 140 89 69 72 68 47 53 70 54 79 82 82 67 68
82 98 115 79 63 53 40 48 65 90 69 79 90 69 94 93 66 57 44 48
40 48 51 43 41 52 49 56 61 77 45

HED-M33B 71

218 153 118 135 113 208 160 117 176 139 272 222 178 142 88 109 163 137 183 121
106 81 85 73 86 114 126 89 81 59 71 53 47 76 54 69 102 79 66 70
87 92 108 77 67 43 47 49 78 81 73 76 85 79 87 85 80 48 49 36
47 41 39 47 46 58 47 49 64 64 68

HED-M34A 58

41 38 40 40 54 45 66 76 49 68 68 63 107 115 76 110 82 94 65 93
81 62 69 66 59 78 82 45 69 76 72 109 79 62 68 90 106 116 102 188
133 110 107 141 137 95 158 93 82 114 91 114 143 122 101 113 122 158

HED-M34B 58

38 35 37 46 48 52 64 81 53 57 63 70 101 110 77 114 86 94 58 89
88 61 72 63 62 87 76 45 63 82 64 105 82 71 60 89 109 116 104 187
146 100 114 139 146 90 145 92 89 110 91 90 150 117 112 119 144 154

HED-M35A 52

226 274 252 299 368 347 339 343 326 177 166 212 248 185 166 242 177 219 173 259
195 194 246 187 163 136 162 172 127 178 238 175 198 176 233 182 181 177 159 309
177 213 230 350 297 185 245 171 209 218 221 262

HED-M35B 52

221 306 217 297 389 324 335 446 252 193 202 200 238 200 182 250 170 229 161 250
208 205 245 177 162 120 178 150 145 179 246 198 206 172 215 173 192 150 196 283
145 216 230 326 382 198 240 180 211 216 221 217

HED-M36A 68

86 110 184 196 272 124 139 138 62 109 235 176 167 126 145 183 182 133 132 150
178 110 144 172 119 96 127 121 116 199 113 106 98 88 63 94 145 147 191 155
135 167 183 174 96 98 126 98 106 99 130 108 136 141 132 178 221 138 76 108
100 71 69 86 74 76 146 160

HED-M36B 68

99 118 179 159 323 94 143 143 67 91 194 187 171 134 127 196 173 180 143 173
149 107 155 169 124 93 141 101 115 182 116 99 96 82 70 104 112 162 181 165
143 201 199 135 122 106 142 100 89 91 158 121 122 146 125 176 247 162 93 114
94 77 73 76 75 74 164 150

HED-M37A 56

52 70 70 51 72 84 76 76 57 64 42 62 74 86 143 103 113 148 135 151
166 218 173 101 227 161 147 90 106 86 158 157 129 107 130 133 133 111 122 114
208 257 210 160 128 138 103 175 106 79 237 156 261 76 58 76

HED-M37B 56

43 72 68 50 69 79 78 71 61 62 53 63 70 77 143 112 104 154 137 147
156 234 173 95 231 161 142 95 101 85 152 162 145 101 140 116 141 109 115 130
206 258 232 148 117 133 87 144 100 87 245 147 274 79 69 82

HED-M38A 66

290 213 205 195 235 304 292 329 245 346 161 204 283 184 276 192 151 190 215 270
251 315 267 206 370 323 212 213 188 236 181 157 199 190 253 162 288 296 266 214
188 214 135 210 215 175 178 294 251 239 149 200 189 220 172 190 299 229 261 292
344 328 253 314 203 339

HED-M38B 66

285 219 177 201 219 328 309 305 259 323 188 213 277 183 209 212 134 175 253 267
310 330 256 197 370 346 202 218 188 219 175 152 164 196 241 201 250 292 227 217
209 175 162 217 216 193 206 259 252 237 160 202 218 202 185 179 284 229 246 304
358 318 247 300 225 253

HED-M39A 69

211 195 145 172 165 123 168 146 193 155 247 219 200 211 225 256 198 217 185 137
130 150 141 132 227 150 231 237 166 191 171 206 140 168 158 150 115 88 67 75
119 110 132 119 131 156 116 107 141 90 80 67 55 72 84 77 71 95 86 70
109 82 78 72 83 77 65 86 69

HED-M39B 69

183 190 157 189 160 112 166 153 180 161 230 196 221 214 230 242 204 200 198 153
120 152 131 136 189 172 263 236 164 213 162 163 157 176 142 153 110 79 79 63
97 99 113 135 132 144 115 112 127 93 84 71 53 65 66 87 61 105 81 75
112 81 61 65 71 70 50 72 92

HED-M40A 77

229 161 252 214 230 240 208 198 196 137 126 157 128 131 191 167 271 238 171 230
174 174 129 173 141 144 119 82 61 65 101 95 123 135 115 152 116 115 131 93
84 70 62 65 75 79 80 99 73 69 117 82 67 60 67 69 51 84 81 83
87 113 108 95 99 83 92 91 62 78 89 83 85 157 138 105 103

HED-M40B 77

241 190 210 211 229 239 202 205 198 134 132 153 136 134 194 168 264 233 156 203
158 188 147 168 145 165 123 78 69 78 92 104 134 125 139 156 123 104 135 95
85 82 64 57 85 84 73 103 70 78 119 73 69 65 85 63 70 88 70 74
105 89 100 106 78 93 96 63 73 100 93 77 152 135 108 78 118

HED-M41A 75

275 164 233 272 254 190 202 259 146 123 93 65 154 252 205 261 223 222 152 161
147 122 124 87 140 146 140 98 113 198 289 254 260 201 227 114 157 132 186 130
186 114 135 113 72 89 85 93 135 100 107 111 125 77 127 97 92 57 49 28
63 55 77 91 62 72 109 104 87 91 108 70 68 68 82

HED-M41B 75

281 147 254 271 246 189 210 245 157 116 95 62 150 244 259 269 214 221 148 161
157 121 117 87 138 150 140 108 115 197 289 245 245 207 211 119 148 135 178 144
167 113 146 84 84 80 93 97 122 94 112 105 105 86 115 88 90 70 38 41
53 52 98 77 74 68 99 125 81 138 92 77 69 77 73

HED-M42A 54

249 349 250 199 251 200 304 273 339 244 268 165 213 248 200 196 206 210 178 195
114 134 157 162 179 192 170 159 161 129 120 98 160 138 109 105 92 101 102 116
88 53 74 61 88 68 86 56 81 65 64 63 70 95

HED-M42B 55

256 333 264 226 251 193 277 279 349 248 252 187 217 255 188 203 212 208 196 200
113 134 154 170 161 198 166 163 154 138 115 109 153 150 105 99 103 101 97 120
74 66 87 59 71 69 79 56 87 65 58 59 69 71 65

HED-M43A 81

137 111 167 140 162 181 173 195 264 222 191 263 148 191 145 146 197 201 327 379
320 244 285 185 175 272 188 218 194 188 194 226 222 324 327 221 158 270 206 181
190 143 164 151 149 187 120 184 141 206 187 180 170 186 197 157 222 178 140 180
172 172 195 181 222 194 190 174 195 271 177 250 214 339 276 227 252 217 237 197
294

HED-M43B 81

152 116 158 141 161 180 192 181 273 218 157 258 143 198 151 147 196 227 319 348
282 258 319 161 171 256 200 207 217 171 185 210 257 319 306 228 158 248 201 178
183 156 150 145 164 176 135 171 135 204 176 180 170 201 209 163 206 194 149 142
156 178 200 177 221 204 193 176 186 247 206 242 211 354 255 239 244 238 239 226
233

HED-M44A 54

152 261 185 183 129 145 205 169 207 217 279 320 275 238 254 326 234 260 331 175
210 148 152 166 260 307 339 252 272 279 121 158 217 189 250 303 159 179 118 186
143 199 185 178 176 194 203 153 222 199 146 142 163 167

HED-M44B 54

122 261 192 175 139 140 207 167 212 183 277 306 262 267 266 336 250 263 312 187
233 161 155 187 227 324 354 261 283 235 144 156 227 192 202 275 148 178 154 157
132 199 179 186 173 200 194 152 202 201 128 155 160 170

HED-M45A 57

218 393 456 417 246 116 71 93 108 116 134 142 119 129 120 155 86 117 147 103
104 65 37 67 52 62 87 97 89 124 115 108 150 142 127 138 109 104 150 181
242 251 236 225 284 259 308 233 270 199 153 28 17 19 65 95 109

HED-M45B 57

211 383 460 416 245 120 67 96 105 122 128 154 104 126 131 145 85 113 146 122
104 71 43 46 55 70 100 94 102 115 119 110 144 138 133 101 125 110 180 178
238 252 242 220 274 251 301 281 271 191 148 20 19 23 69 97 104

HED-M46A 54

397 450 425 239 118 80 88 109 121 121 144 124 133 105 145 100 109 142 100 98
73 43 47 60 68 91 102 91 119 110 110 144 139 130 92 134 122 147 152 261
280 240 223 308 262 302 268 256 197 154 29 22 28 73

HED-M46B 54

388 456 423 236 129 54 99 104 120 134 138 118 132 103 130 95 111 116 101 105
68 47 39 56 68 94 94 91 130 111 110 137 136 123 110 122 120 137 177 259
291 228 238 303 247 306 252 277 185 144 22 22 26 57

HED-M47A 55

407 362 381 359 416 337 475 304 218 305 349 359 253 226 130 113 71 81 62 104
152 179 155 160 239 219 264 284 280 333 134 149 137 105 104 70 68 87 63 152
248 246 321 342 345 231 314 459 359 378 388 378 345 421 223

HED-M47B 55

395 364 346 411 401 365 453 321 244 285 330 311 282 253 162 117 83 75 58 101
141 115 162 156 272 210 284 223 271 246 155 150 122 121 112 69 60 77 84 144
212 264 341 292 294 214 324 480 363 373 384 382 351 402 252

HED-M48A 56

274 294 404 193 119 293 290 387 151 153 235 318 378 104 108 62 68 48 85 224
139 310 397 245 266 232 273 256 233 364 347 224 245 314 246 179 177 204 212 171
141 260 137 192 252 230 188 170 218 234 155 147 244 186 162 270

HED-M48B 56

226 299 417 141 104 275 293 395 122 95 227 334 391 108 102 70 68 43 78 234
152 330 393 227 253 233 302 244 245 368 353 219 222 299 246 175 162 212 217 137
157 245 177 178 253 225 208 176 282 231 160 158 264 146 168 268

HED-M49A 50

531 358 425 257 259 191 216 311 320 262 253 317 517 503 358 291 184 189 263 288
265 202 243 288 184 126 100 192 160 212 191 136 161 162 117 142 155 151 155 222
174 140 236 202 285 244 226 207 222 177

HED-M49B 50

550 365 460 275 266 214 208 270 319 248 269 331 551 512 365 287 197 181 265 273
256 225 263 250 203 119 115 199 173 211 187 124 136 152 105 156 144 156 149 210
175 143 239 211 274 249 213 192 245 159

HED-M50A 57

386 675 669 596 577 552 390 421 254 270 201 194 267 342 251 254 343 555 502 360
281 183 196 262 272 282 187 273 252 202 107 125 170 178 190 198 116 161 141 114
140 152 154 147 210 175 136 243 220 278 248 212 199 239 159 228 210

HED-M50B 57

408 655 618 586 607 588 345 422 244 265 198 227 291 320 264 269 346 505 503 369
265 183 193 280 260 259 204 265 262 214 120 108 185 171 192 186 139 144 141 110
144 145 161 155 209 175 148 224 228 270 242 233 187 240 180 208 216

HED-M51A 55

149 252 296 104 159 190 170 122 120 188 209 170 121 192 171 150 141 133 118 195
263 125 147 178 159 162 182 145 148 146 113 87 80 118 75 74 160 210 114 109
90 77 94 116 91 81 127 78 71 87 125 82 84 134 137

HED-M51B 55

152 269 278 104 161 205 162 117 134 169 214 185 112 206 172 160 139 136 107 175
249 129 139 175 169 163 180 155 143 150 105 90 75 118 72 70 162 190 118 121
93 77 99 105 97 87 127 85 67 96 123 71 97 142 127

HED-M52A 57

119 133 119 129 76 96 102 109 76 53 67 78 71 64 65 71 64 74 73 63
68 65 55 53 54 68 66 66 85 122 76 99 94 95 64 124 166 181 347 333
263 203 126 105 140 171 207 182 228 195 167 139 143 145 120 155 163

HED-M52B 57

99 126 113 132 68 103 88 117 90 58 66 79 70 71 66 73 60 72 71 63
69 67 58 50 57 74 58 67 83 116 79 100 99 89 68 117 173 170 345 343
253 186 133 110 139 166 204 176 225 207 177 139 143 148 116 138 159

HED-M53A 54

114 113 111 87 154 108 87 128 142 107 100 116 126 123 97 154 147 141 154 169
145 150 123 149 165 224 304 145 118 105 132 132 120 90 109 129 100 92 146 144
134 186 166 116 157 154 117 138 129 160 161 206 216 200

HED-M53B 54

126 106 123 78 138 123 80 123 144 109 101 114 125 136 90 151 150 145 147 171
141 146 128 153 152 234 278 159 125 105 119 146 102 106 105 124 98 93 152 140
141 179 176 111 163 141 125 139 140 158 168 198 225 188

HED-M54A 56

421 508 444 391 564 465 201 201 200 260 249 465 342 189 255 251 295 312 252 222
235 204 190 216 215 144 178 290 263 349 349 295 448 351 285 320 320 186 191 181
179 249 233 325 262 264 225 185 204 378 535 429 448 565 449 311

HED-M54B 56

444 506 402 381 579 410 221 240 157 253 272 528 343 189 224 281 282 308 272 239
280 207 195 193 219 125 194 269 265 336 328 287 472 363 291 324 290 206 200 174
177 262 222 313 244 245 211 200 207 373 522 430 451 550 441 335

HED-M55A 57

213 116 125 105 149 163 157 122 138 137 153 206 139 177 268 458 359 182 239 221
147 163 110 152 137 132 127 165 161 73 131 101 147 199 176 146 217 153 131 135
148 117 163 162 125 114 126 191 150 127 106 110 139 101 131 138 151

HED-M55B 57

229 129 114 78 164 159 153 114 140 147 127 224 137 190 312 448 328 187 219 243
131 159 113 146 130 139 131 163 154 75 111 105 158 207 176 128 234 144 151 120
137 119 170 177 103 100 135 217 142 130 114 128 125 99 106 138 173

HED-M56A 56

360 468 469 384 252 250 260 358 252 270 293 310 341 243 199 199 256 231 243 245
232 206 186 191 171 150 196 183 95 128 168 144 110 99 51 69 93 88 80 103
73 74 56 41 63 100 108 74 55 83 111 113 103 79 80 87

HED-M56B 56

354 458 475 390 254 249 256 338 251 273 307 312 316 266 201 215 257 218 240 229
253 195 191 199 155 147 200 173 94 149 175 141 111 95 55 66 95 92 68 100
86 79 47 38 69 90 118 84 49 71 103 115 99 100 70 78

HED-M57A 95

132 171 114 104 114 76 108 109 120 99 147 152 165 173 123 189 143 163 138 135
126 167 103 100 127 173 211 234 205 216 169 189 160 169 121 92 98 106 133 144
185 170 117 143 152 123 200 129 150 106 103 132 159 131 116 123 129 120 169 97
134 135 121 116 127 112 112 85 126 89 90 93 88 84 106 93 80 131 135 91
173 181 108 128 98 130 110 104 105 145 207 120 121 83 167

HED-M57B 95

157 150 118 105 118 72 98 119 131 88 157 140 183 162 132 177 153 166 150 137
123 147 126 96 135 185 235 225 187 220 163 187 159 153 146 86 105 103 132 137
183 173 111 131 149 132 201 131 164 97 98 137 161 132 103 146 126 104 156 106
126 132 122 111 135 112 114 77 122 99 88 95 78 84 109 99 79 136 132 94
168 166 128 123 103 132 106 110 103 127 209 115 111 91 169

HED-M58A 66

193 183 176 169 240 238 181 266 155 236 144 84 146 147 114 125 196 126 107 185
143 166 161 186 198 171 216 253 226 259 177 197 162 123 135 124 95 85 140 98
91 171 175 126 191 148 168 182 153 147 205 249 195 178 203 432 364 240 243 237
188 222 165 185 202 269

HED-M58B 66

171 194 176 167 245 234 191 248 179 215 155 94 141 132 113 122 199 117 115 178
134 164 174 182 208 178 209 241 213 246 172 189 159 123 131 134 102 74 137 99
87 192 165 136 191 141 169 174 157 147 197 252 175 190 207 438 364 253 207 257
225 208 154 170 219 278

HED-M59A 81

401 283 343 283 193 160 119 186 137 176 172 153 206 236 158 165 138 112 125 132
115 95 106 105 143 132 140 193 193 169 229 214 124 108 126 176 167 197 182 155
158 154 188 195 156 168 166 185 227 198 165 174 263 216 246 174 155 151 129 104
166 141 117 99 81 88 86 91 142 139 135 92 103 99 130 125 146 99 105 99
146

HED-M59B 81

382 279 350 280 195 161 111 187 152 175 180 162 209 239 151 175 134 103 125 134
119 86 105 106 142 130 142 176 195 171 227 222 119 115 131 178 168 193 173 140
165 162 180 202 153 173 164 186 209 178 169 190 267 222 274 170 162 161 138 109
155 150 101 93 93 100 101 94 124 136 139 103 99 109 131 123 157 106 110 130
128

HED-M60A 79

212 192 227 107 173 187 128 184 187 171 196 174 137 151 220 195 295 222 148 190
231 141 129 141 180 204 236 143 155 168 186 126 152 112 104 129 159 149 171 195
210 256 246 219 245 216 201 182 215 246 186 167 186 168 196 227 223 252 231 191
179 217 167 203 252 248 202 181 215 190 181 195 157 169 143 198 206 174 201

HED-M60B 79

197 197 226 105 165 186 130 178 189 171 187 168 161 152 214 188 303 222 154 188
230 138 137 133 180 220 233 165 131 155 168 103 136 134 108 137 151 143 157 200
227 253 229 242 240 215 188 222 214 236 192 155 174 180 173 233 220 257 227 195
179 227 151 223 256 254 206 173 209 195 179 192 159 150 148 187 191 172 189

HED-M61A 55

414 392 323 320 209 217 316 287 227 276 397 327 371 369 282 378 238 184 258 161
236 212 269 238 173 149 176 262 275 384 379 368 390 290 238 269 306 230 266 199
199 185 190 213 222 208 204 197 176 262 207 142 96 157 158

HED-M61B 55

418 368 345 310 226 252 292 310 210 285 407 343 382 375 289 383 233 185 246 179
231 220 262 225 169 157 173 283 276 389 384 383 413 268 271 274 272 274 247 233
201 198 191 207 221 207 207 192 182 247 202 191 94 139 155

HED-M62A 54

481 602 557 137 136 222 266 150 294 298 104 196 176 183 183 286 335 287 234 175
224 235 500 590 541 503 616 549 247 131 300 283 234 309 308 230 179 235 213 232
229 226 104 116 106 173 176 187 182 304 290 182 299 294

HED-M62B 54

497 614 552 135 133 226 262 148 301 296 118 204 169 191 170 299 331 277 257 174
225 225 502 596 549 510 609 538 266 147 301 288 240 173 228 227 233 216 234 105
84 123 191 169 187 172 297 317 139 307 331 168 283 318

HED-M63A 55

257 166 264 240 286 316 207 147 169 270 293 257 287 184 178 264 436 335 281 265
325 433 328 422 333 385 335 402 354 357 249 197 256 234 241 282 184 176 350 408
370 269 298 298 409 394 383 324 425 309 385 331 416 293 333

HED-M63B 55

227 179 258 252 268 321 223 187 183 209 289 243 306 185 176 256 442 347 258 260
346 420 343 404 327 396 317 415 360 347 248 200 261 228 236 283 179 197 329 413
392 261 287 307 409 383 388 342 407 326 360 338 420 312 342

HED-M64A 55

252 210 230 143 245 164 164 232 204 342 151 185 212 258 263 178 226 135 188 160
193 276 204 271 232 297 129 150 269 190 220 222 265 251 251 233 146 117 193 93
157 146 156 123 168 165 196 110 155 229 185 224 142 242 128

HED-M64B 55

224 198 229 151 247 164 159 227 208 341 156 174 210 255 255 202 201 156 192 146
208 283 201 259 244 277 147 145 272 185 201 226 268 247 270 233 171 126 187 90
160 159 158 126 168 164 192 117 164 234 181 231 134 239 136

HED-M65A 56

221 195 143 244 201 338 148 186 218 256 260 190 211 147 185 131 225 287 216 262
213 303 146 133 280 194 222 213 276 254 256 225 174 110 196 231 137 172 124 158
172 206 120 151 232 181 234 143 242 175 169 127 100 149 137 160

HED-M65B 56

243 159 169 227 211 332 149 179 221 258 256 185 219 133 188 163 216 287 180 300
226 261 139 143 278 190 194 224 276 246 273 205 170 111 201 245 135 150 125 158
178 192 116 159 236 168 232 140 250 161 172 137 109 142 124 165

HED-M66A 54

401 208 193 231 214 198 187 326 357 308 316 266 276 275 230 281 245 299 259 218
189 220 211 212 142 122 188 191 142 183 202 212 185 212 251 230 214 225 158 197
205 120 146 168 132 131 157 203 292 262 220 186 249 177

HED-M66B 54

404 197 182 223 212 213 173 324 342 292 336 253 261 298 236 296 253 264 293 217
199 220 222 181 145 141 182 204 123 187 207 214 185 207 243 270 214 206 171 209
175 144 159 152 165 134 160 202 299 279 205 184 238 184

HED-M67A 55

174 213 273 217 246 269 203 173 163 188 201 126 197 193 175 75 135 146 128 191
135 91 95 109 86 86 60 68 89 67 44 65 95 88 110 128 193 199 251 276
175 125 164 185 244 208 227 227 242 297 219 241 276 187 150

HED-M67B 55

174 208 240 264 259 244 204 166 200 202 199 115 187 188 170 82 126 160 115 187
129 101 92 104 101 91 49 67 95 56 48 63 98 87 114 129 199 192 258 262
170 136 156 197 244 199 222 224 241 273 234 285 260 193 192

HED-M68A 54

257 135 195 207 269 122 125 105 127 234 139 146 121 255 152 191 235 344 197 233
235 309 248 181 303 291 259 275 230 218 217 159 120 175 125 130 123 120 92 112
164 174 130 156 161 148 197 110 112 83 96 106 106 111

HED-M68B 54

194 147 188 212 252 120 128 100 112 224 126 144 119 223 163 222 189 314 176 233
232 303 227 197 335 281 259 268 236 253 227 158 125 165 142 135 121 123 94 96
168 177 148 156 176 136 205 98 106 92 90 100 104 109

HED-M69A 50

189 188 149 184 120 144 146 183 197 239 249 302 297 410 218 316 305 307 343 347
300 234 188 235 169 191 144 172 188 195 169 148 160 131 109 99 158 162 134 162
135 169 130 175 136 186 127 104 153 118

HED-M69B 50

171 202 129 194 130 139 127 218 173 248 244 299 296 408 217 306 309 329 342 342
302 247 196 204 181 181 129 213 185 155 184 135 156 134 109 97 152 129 139 135
155 165 136 177 142 151 133 102 138 181

HED-M70A 48

204 223 197 242 321 286 205 211 243 243 291 208 232 208 192 177 187 141 119 120
125 179 136 128 85 107 146 103 97 116 82 145 159 140 125 159 207 211 189 246
195 180 205 232 152 157 183 135

HED-M70B 48

193 223 192 242 297 285 198 209 233 306 293 192 240 200 196 175 187 141 117 127
133 149 149 127 93 128 131 100 107 97 115 153 154 156 145 155 190 206 201 227
191 193 234 226 140 147 193 138

HED-M71A 52

141 127 149 130 182 234 83 209 442 243 227 121 162 418 291 335 307 161 133 194
86 74 115 112 73 39 116 82 118 131 76 213 192 213 163 203 224 289 320 358
362 200 199 233 268 334 206 216 278 412 376 232

HED-M71B 52

124 130 158 116 188 235 94 202 436 239 246 103 178 401 294 336 308 157 118 188
90 78 89 129 72 45 110 79 115 135 87 216 200 204 160 191 202 301 354 367
382 197 227 227 282 328 200 211 264 441 394 215

HED-M72A 47

232 140 132 168 141 147 92 149 62 71 69 36 92 87 122 135 166 331 215 410
438 279 184 252 318 283 236 229 248 232 350 308 294 246 212 174 153 212 200 210
109 172 161 166 144 93 97

HED-M72B 47

217 145 118 184 138 140 104 143 64 71 71 36 90 81 130 140 181 313 222 373
430 286 195 226 328 283 236 225 262 241 354 358 334 301 211 200 161 223 195 203
115 169 154 163 153 110 69

HED-M73A 57

90 104 118 95 93 74 81 92 160 141 151 128 124 131 241 223 150 145 136 130
84 84 106 108 82 118 74 85 103 97 94 88 69 71 141 94 113 110 120 83
92 96 122 104 118 83 104 118 79 105 109 104 156 117 62 121 103

HED-M73B 57

65 107 106 98 100 77 80 93 147 153 160 137 130 120 240 223 138 141 130 120
91 95 90 129 78 87 86 73 117 106 79 93 68 75 141 98 110 117 115 82
90 91 128 105 105 90 84 111 96 107 111 107 134 111 85 111 104

HED-M74A 58

409 560 255 215 221 269 194 238 223 361 343 267 320 336 294 293 329 151 152 107
89 105 172 115 98 121 106 99 66 124 147 133 74 73 52 52 40 43 33 28
24 44 40 38 51 84 98 60 84 93 61 44 38 47 66 54 51 48

HED-M74B 58

389 534 277 227 186 271 205 231 241 366 343 244 339 346 290 308 330 153 145 103
92 108 170 118 89 128 110 94 69 110 146 154 69 72 67 40 42 40 36 31
24 26 38 43 66 77 104 69 74 93 70 35 36 46 59 60 52 48

HED-M75A 56

402 223 333 284 542 579 716 644 695 648 606 384 425 507 445 486 189 178 182 142
107 121 139 183 114 196 182 281 211 321 233 301 283 279 267 237 197 180 170 175
173 215 158 187 146 179 175 244 242 170 219 164 164 183 183 160

HED-M75B 56

399 245 369 310 509 583 707 654 705 656 600 381 421 506 457 474 197 173 186 152
95 122 145 178 110 202 188 257 221 292 221 309 302 257 282 228 200 185 169 174
156 230 196 187 157 186 170 236 229 183 203 170 169 186 181 165

HED-M76A 56

371 319 319 225 271 279 342 336 334 269 286 248 293 187 198 227 270 159 170 177
197 206 272 231 267 323 294 243 294 260 252 253 299 263 339 398 378 324 210 192
130 191 204 240 229 216 207 259 216 243 290 268 243 249 210 182

HED-M76B 56

321 316 325 241 274 281 335 343 333 284 298 211 270 198 202 240 239 158 207 186
178 203 294 203 288 332 302 268 299 267 252 266 303 248 321 398 385 323 208 189
132 188 199 234 222 230 230 232 248 232 277 296 240 245 209 180

HED-M77A 57

308 339 309 176 138 166 210 162 155 166 195 172 175 146 159 127 96 73 80 116
64 48 49 40 33 29 21 38 28 30 30 24 47 71 124 133 158 244 172 146
90 88 124 206 178 242 128 50 44 41 50 48 43 84 141 88 85

HED-M77B 57

276 322 301 172 140 173 220 188 177 150 191 185 173 143 165 110 105 76 80 102
75 39 41 42 37 31 22 34 31 27 26 30 44 74 121 127 152 259 133 135
94 86 117 198 174 259 131 47 52 50 40 50 39 84 150 78 81

HED-M78A 54

88 103 135 121 142 122 194 204 213 238 235 219 160 119 181 278 242 182 147 126
119 134 179 269 185 273 217 221 183 225 246 232 185 264 323 352 303 358 304 178
105 70 104 94 152 97 106 97 174 143 115 187 173 144

HED-M78B 54

86 97 117 112 158 110 176 210 191 222 236 230 163 122 177 301 241 177 130 119
137 134 179 279 191 253 218 223 189 228 259 227 184 249 338 368 293 368 300 192
100 83 108 83 162 106 104 95 143 158 123 178 176 145

HED-M79A 53

189 156 151 93 94 113 90 134 166 109 154 103 75 57 59 71 58 66 68 71
97 103 118 115 121 143 112 97 90 94 93 100 129 103 109 128 194 107 170 127
95 147 129 127 104 104 145 140 114 106 116 92 62

HED-M79B 53

209 153 161 89 98 107 99 129 166 106 160 93 76 64 50 76 58 66 68 65
103 101 120 111 124 140 119 95 106 90 93 105 124 113 107 129 208 99 168 114
98 140 126 124 105 108 144 135 120 101 108 96 77

HED-M80A 58

74 94 57 55 73 84 111 95 82 59 65 90 76 77 91 66 54 54 64 43
46 51 51 52 54 77 77 73 70 63 63 56 64 90 72 77 77 76 71 77
61 61 85 70 121 88 82 112 94 120 127 126 137 107 128 106 90 99

HED-M80B 58

72 81 65 58 71 82 114 96 76 60 77 72 79 80 92 67 62 50 62 46
51 51 58 60 53 74 81 67 80 51 69 62 67 96 72 77 81 74 68 72
61 73 80 79 105 91 81 109 84 110 128 136 120 92 124 99 96 102

HED-M81A 59

20 30 27 16 31 23 33 28 45 51 36 56 51 95 93 89 114 84 89 95
121 73 124 103 133 90 72 90 61 70 75 98 99 69 89 68 101 95 87 117
162 128 149 118 168 182 118 100 101 175 168 110 115 133 100 123 97 91 96

HED-M81B 54

35 29 27 28 40 36 36 40 55 90 104 94 109 79 98 95 155 65 121 88
158 83 78 67 73 103 84 87 99 59 78 80 86 97 88 114 167 141 144 117
177 184 116 105 102 173 158 114 113 145 109 125 109 92

HED-M82A 80

259 118 129 160 106 218 145 251 165 200 171 105 168 137 101 122 112 124 106 79
119 72 50 60 54 71 115 91 97 126 115 99 81 81 105 86 92 70 62 38
63 41 35 53 66 44 42 35 29 23 27 38 53 40 46 52 87 79 46 51
30 37 35 28 30 34 61 52 42 32 33 32 32 42 44 36 36 35 54 102

HED-M82B 80

263 113 131 171 106 219 140 242 174 202 173 114 161 133 106 116 122 107 122 82
138 75 50 72 60 86 114 98 92 108 126 97 85 78 103 80 93 70 68 37
53 40 34 58 58 49 40 32 30 30 26 38 44 35 59 56 86 84 44 50
41 33 42 30 26 42 51 58 38 33 28 31 35 44 45 34 38 35 53 95

HED-M83A 47

249 251 266 188 233 197 160 256 172 194 177 190 200 263 396 354 270 221 194 311
238 231 324 148 185 252 323 311 248 261 287 299 108 128 216 224 210 203 189 227
221 212 222 102 171 158 159

HED-M83B 47

261 240 266 197 224 202 163 262 157 195 158 205 184 247 400 340 274 222 212 308
253 212 318 155 180 260 330 306 268 277 291 304 118 125 216 215 214 204 187 235
213 223 233 100 153 176 183

HED-M84A 36

141 106 151 130 178 300 237 306 290 336 251 226 356 299 307 331 327 303 325 275
289 357 193 124 168 203 208 191 179 152 133 125 152 86 90 138

HED-M84B 33

409 429 336 292 411 247 216 235 287 306 248 244 302 335 157 123 185 174 177 147
181 155 146 126 152 104 115 113 106 108 67 64 92

HED-M85A 55

62 40 46 51 89 206 221 132 133 96 148 171 235 167 255 237 148 122 136 191
162 193 225 115 125 72 81 93 79 84 110 125 91 108 141 144 133 105 139 104
83 64 60 49 109 161 148 141 236 148 177 156 89 90 116

HED-M85B 48

88 155 146 86 115 120 172 104 106 60 44 69 88 160 148 125 186 99 151 154
241 200 223 157 134 103 156 154 164 166 121 83 132 79 100 106 83 94 89 110
90 102 167 125 163 120 120 116

HED-M86A 38

192 395 259 282 428 177 305 285 339 254 301 339 184 212 212 181 220 208 127 81
124 80 76 88 48 85 90 68 52 81 83 66 88 91 63 77 55 83

HED-M86B 38

294 379 242 287 422 209 289 291 338 252 313 325 191 206 217 174 227 190 131 75
127 81 72 87 54 94 80 84 56 70 78 65 94 93 65 71 42 69

HED-M87A 42

121 217 250 325 166 307 312 261 251 165 199 209 202 228 220 217 235 188 196 158
135 181 145 194 197 248 276 266 301 321 277 405 426 263 214 297 275 298 375 343
322 278

HED-M87B 42

132 227 268 329 168 317 303 255 247 166 188 215 203 248 200 237 240 174 173 157
148 174 162 187 209 264 246 279 279 330 258 405 418 259 225 303 275 311 389 356
319 280

HED-M88A 18

573 599 736 497 499 352 245 243 302 322 298 172 132 141 186 205 180 125

HED-M88B 18

563 611 718 484 492 352 239 242 295 330 300 174 135 141 188 201 164 157

HED-M89A 51

211 202 156 240 254 160 187 180 212 200 350 414 266 321 249 311 469 503 416 160
330 236 206 173 163 191 163 150 110 144 149 151 238 225 247 203 118 117 176 134
201 214 139 162 198 142 242 238 148 133 240

HED-M89BB 51

159 198 164 234 245 158 183 163 203 212 353 418 263 316 251 314 485 512 402 148
337 238 207 172 163 191 157 150 110 132 153 166 236 224 248 210 113 122 169 133
209 214 145 167 193 134 253 238 159 130 249

HED-M90A 63

399 424 269 430 391 438 533 301 436 711 383 428 463 553 343 441 374 299 345 299
306 304 338 279 254 233 234 241 292 233 299 232 259 263 284 224 230 275 209 265
184 169 134 179 178 220 256 209 269 253 150 231 224 131 104 154 198 218 271 257
255 183 222

HED-M90B 63

394 415 269 502 399 450 513 326 446 716 385 421 470 534 321 439 383 292 332 286
288 324 324 260 264 299 231 245 282 226 288 236 264 263 279 231 226 269 203 264
183 166 130 189 175 209 258 202 260 240 145 223 208 146 93 145 190 221 274 257
261 177 230

HED-M91A 29

194 270 316 397 417 413 558 421 542 533 485 333 398 397 465 481 425 371 292 411
369 440 303 435 429 425 538 488 382

HED-M91B 29

179 265 313 386 462 455 578 402 536 543 485 330 385 402 454 474 405 371 276 400
403 419 322 421 434 444 518 493 382

HED-M92A 52

285 244 298 203 282 257 236 241 177 192 221 221 259 162 219 175 197 180 140 195
156 192 163 223 165 130 151 81 108 133 118 142 191 133 134 152 182 183 163 144
148 146 73 91 125 118 174 204 198 181 180 132

HED-M92B 50

478 423 543 584 372 341 399 230 292 362 366 185 239 236 192 206 171 145 140 158
133 87 127 158 134 155 165 206 271 214 144 230 174 152 157 104 126 142 83 89
151 109 128 186 156 158 175 124 157 198

HED-M93A 33

375 280 759 345 215 235 122 158 156 220 277 243 159 173 159 208 327 172 210 164
213 139 260 206 193 245 196 250 235 227 189 260 290

HED-M93B 33

346 283 754 274 217 223 105 157 156 202 275 238 144 179 168 198 320 182 222 161
212 151 269 204 188 233 187 250 216 228 192 240 336

HED-M94A 39

426 449 488 372 495 467 329 366 403 337 642 506 210 172 328 396 394 425 318 382
262 299 299 556 368 362 475 373 370 444 285 287 317 300 278 328 370 337 281

HED-M94B 39

400 415 497 381 505 453 339 355 415 305 655 517 248 179 346 360 394 421 342 381
253 282 318 558 381 365 450 368 364 465 255 263 341 283 280 330 373 273 265

HED-M95A 23

552 569 513 524 546 595 376 496 418 446 447 372 423 455 616 493 399 400 480 525
278 330 355

HED-M95B 23

604 573 542 509 554 622 380 481 467 433 440 368 400 464 641 515 381 414 504 527
266 356 354

HED-M96A 39

530 258 272 377 576 646 572 439 567 542 522 543 191 278 292 360 382 461 311 347
443 537 515 420 492 430 411 390 437 651 651 616 622 602 486 340 139 386 347

HED-M96B 39

561 247 268 371 546 635 537 462 490 611 498 569 192 274 289 346 357 484 309 336
437 556 507 410 498 437 403 393 425 661 652 636 587 638 512 337 132 386 338

HED-M97A 35

361 436 407 313 207 343 258 300 377 336 239 173 200 168 191 145 129 137 183 128
145 128 134 131 141 148 125 106 113 93 137 117 118 104 136

HED-M97B 35

353 433 407 313 212 329 273 294 386 312 231 174 199 173 177 158 119 134 183 133
155 140 124 138 124 143 130 103 108 97 138 117 125 104 119

HED-M98A 35

533 423 524 498 529 339 241 248 321 603 467 228 391 316 268 295 229 152 207 169
132 134 113 146 224 177 147 101 123 94 171 107 153 167 150

HED-M98B 35

526 429 524 490 525 366 246 247 351 610 457 217 397 321 265 313 238 171 205 176
160 118 108 144 218 180 143 106 117 113 172 112 117 169 160

HED-M99A 66

42 31 47 45 56 44 38 39 43 50 54 50 52 64 46 42 27 28 30 39
60 65 128 142 159 132 146 224 204 182 171 248 221 332 278 201 181 250 225 191
197 237 134 138 213 315 313 359 406 427 433 370 294 346 254 206 254 202 275 274
228 200 262 246 262 242

HED-M99B 66

53 35 45 45 56 41 41 42 52 48 48 51 56 51 44 45 23 29 29 37
63 67 131 138 169 133 143 247 194 211 152 250 228 382 293 193 184 246 240 207
202 232 130 141 217 326 270 372 397 424 445 373 291 340 286 190 241 165 248 243
205 206 252 235 259 267

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 Buildings*' (Laxton and Litton 1988b) and, for example, in *Tree-Ring Dating and Archaeology* (Baillie 1982) or *A Slice Through Time* (Baillie 1995). 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 1 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, 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 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 1, 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. 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 University of Nottingham Tree-Ring dating Laboratory

1. *Inspecting the Building and Sampling the Timbers.* Together with a building historian we inspect the timbers in a building 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 2 has about 120 rings; about 20 of which are sapwood rings. Similarly the core has just over 100 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 to 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.

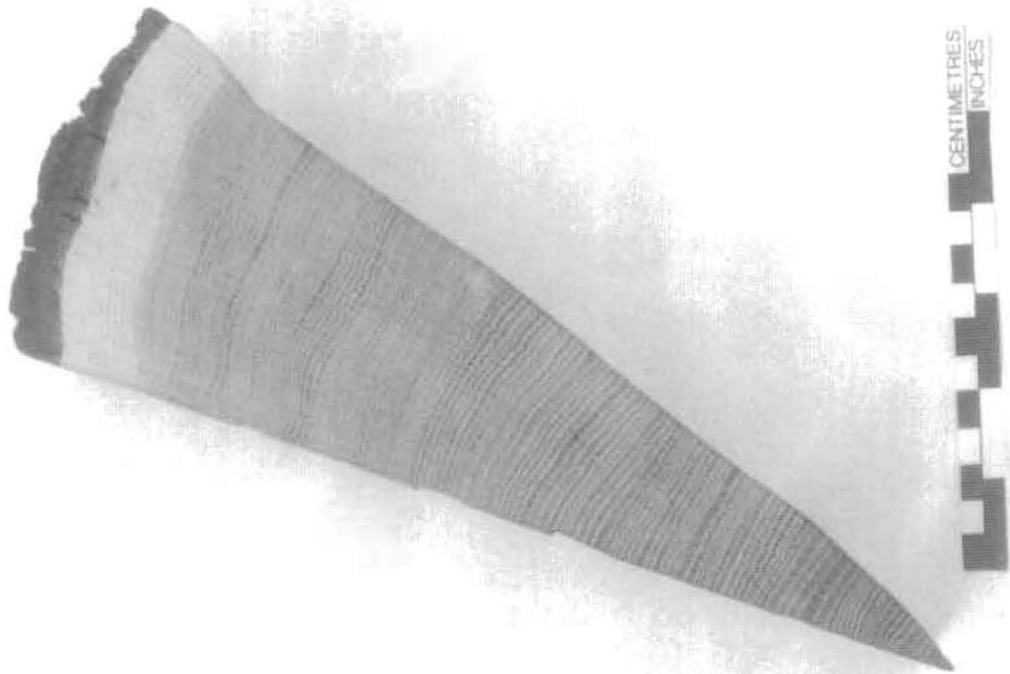


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

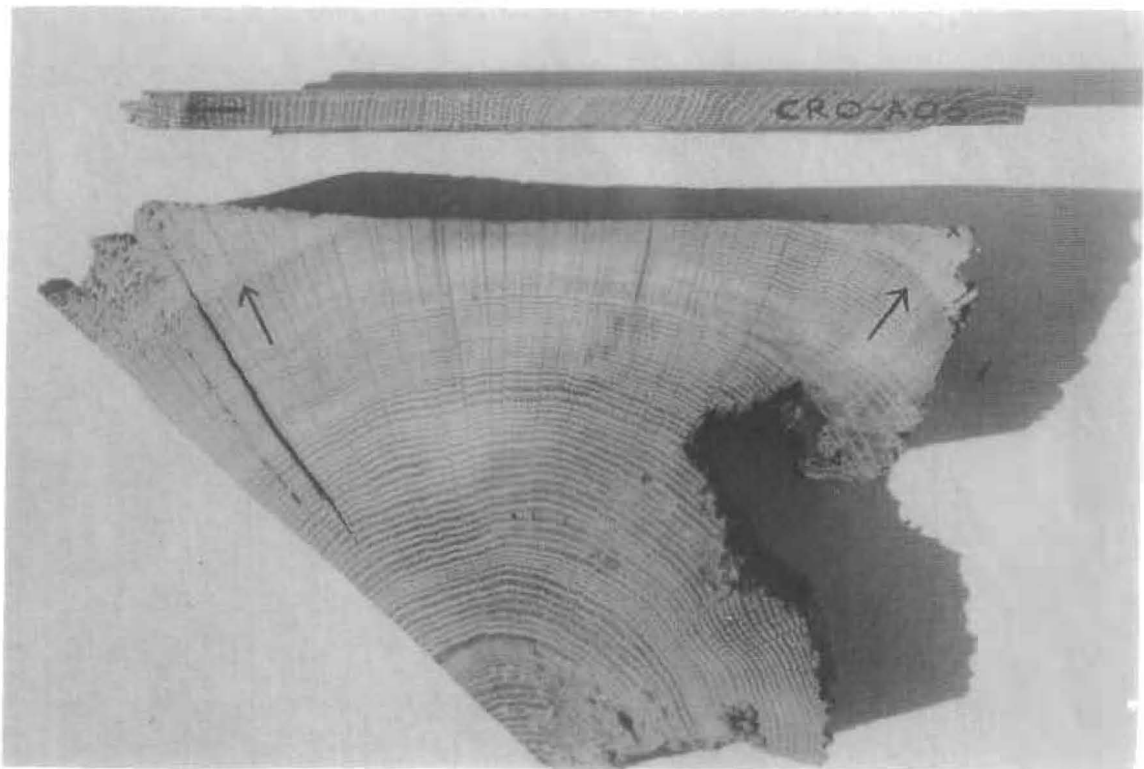


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.



Fig 3. 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.

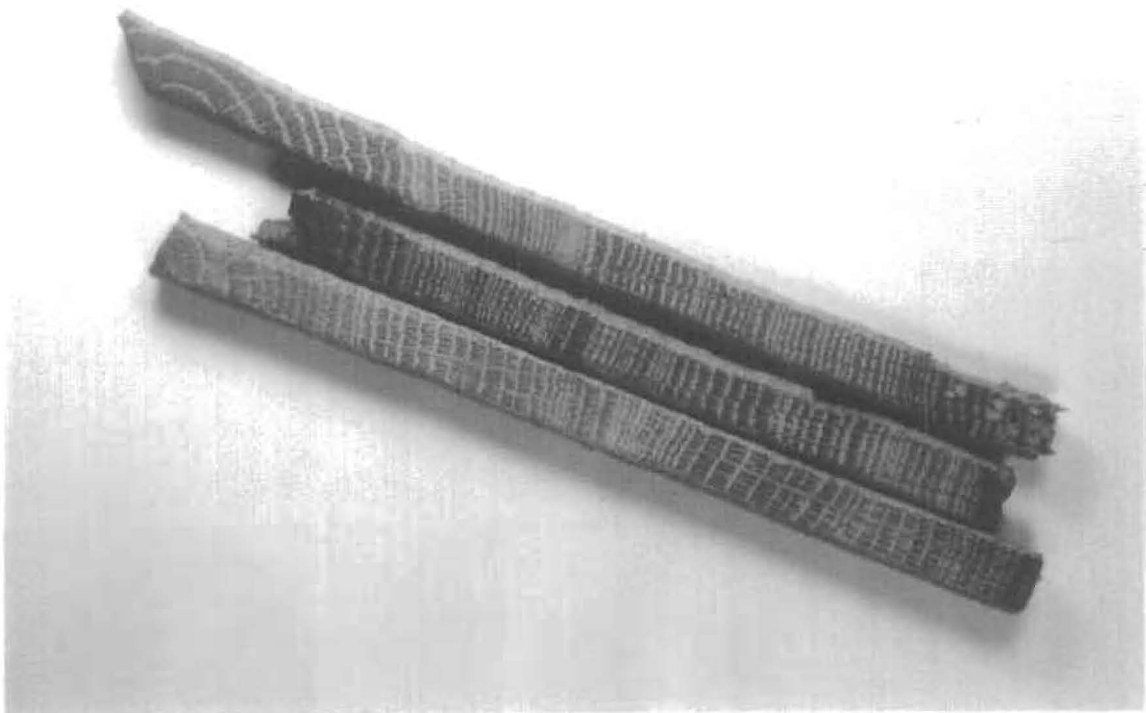


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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 2; it is about 15cm long and 1cm diameter. Great care has to be taken to ensure that as few as possible of the outer rings are lost. 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 is insured with the CBA.

- 2. Measuring Ring Widths.** Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure 2. 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 3).
- 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 4). 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 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton *et al* 1988a,b; Howard *et al* 1984 - 1995).

This is illustrated in Fig 5 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. C08 matches C45 best when it is at a position starting 20 rings after the first ring of 45, 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 between these two whatever the position of one sequence relative to the other.

It is standard practice in our Laboratory first to cross-match as many as possible of the 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 Fig 5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences from 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. 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.

average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

This 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'. This was developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988a). To illustrate the difference between the two approaches with the above example, consider sequences C08 and C05. They are the most similar pair with a t-value of 10.4. Therefore, these two are first averaged with the first ring of C05 at +17 rings relative to C08 (the offset at which they match each other). This average sequence is then used in place of the individual sequences C08 and C05. The cross-matching continues in this way gradually building up averages at each stage eventually to form the site sequence.

4. ***Estimating the Felling Date.*** If the bark is present on a sample, then the date of its last ring is the date of the felling of its tree. Actually it could be the year after if it had been felled in the first three months 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, they can be seen in two upper corners of the rafter and at the outer end of the core in Figure 2. 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 for 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. Thus in these circumstances the date of the present last ring is at least close to the date of the original last ring on the tree, and so to the date of felling.

Various estimates have been made for the average number of sapwood rings in a mature oak. One estimate is 30 rings, based on data from living oaks. So, in the case of the core in Figure 2 where 9 sapwood rings remain, this would give an estimate for the felling date of 21 ($= 30 - 9$) years later than of the date of the last ring on the core. Actually, it is better in these situations to give an estimated range for the felling date. Another estimate is that in 95% of mature oaks there are between 15 and 50 sapwood rings. So in this example this would mean that the felling took place between 6 ($= 15 - 9$) and 41 ($= 50 - 9$) years after the date of the last ring on the core and is expected to be right in at least 95% of the cases (Hughes *et al* 1981; see also Hillam *et al* 1987).

Data from the Laboratory has shown that when sequences are considered together in groups, rather than separately, the estimates for the number of sapwood can be put at between 15 and 40 rings in 95% of the cases with the expected number being 25 rings. We would use these estimates, for example, in calculating the range for the common felling date of the four sequences from Lincoln Cathedral using the average position of the heartwood/sapwood boundary (Fig 5). These new estimates are now used by us in all our publications except for timbers from Kent and Nottinghamshire where 25 and between 15 to 35 sapwood rings, respectively, is used instead (Pearson 1995).

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 2 was taken still had complete sapwood. Sapwood rings were only lost in coring, because of their softness. By measuring in the timber the depth of sapwood lost, say 2 cm., a reasonable estimate can be made of the number of sapwood rings missing from the core, 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 40 years later we would have estimated without this observation.

T-value/Offset Matrix

| | C45 | C08 | C05 | C04 |
|-----|-----|------|-----|-----|
| C45 | | +20 | +37 | +47 |
| C08 | 5.6 | | +17 | +27 |
| C05 | 5.2 | 10.4 | | +10 |
| C04 | 5.9 | 3.7 | 5.1 | |

Bar Diagram

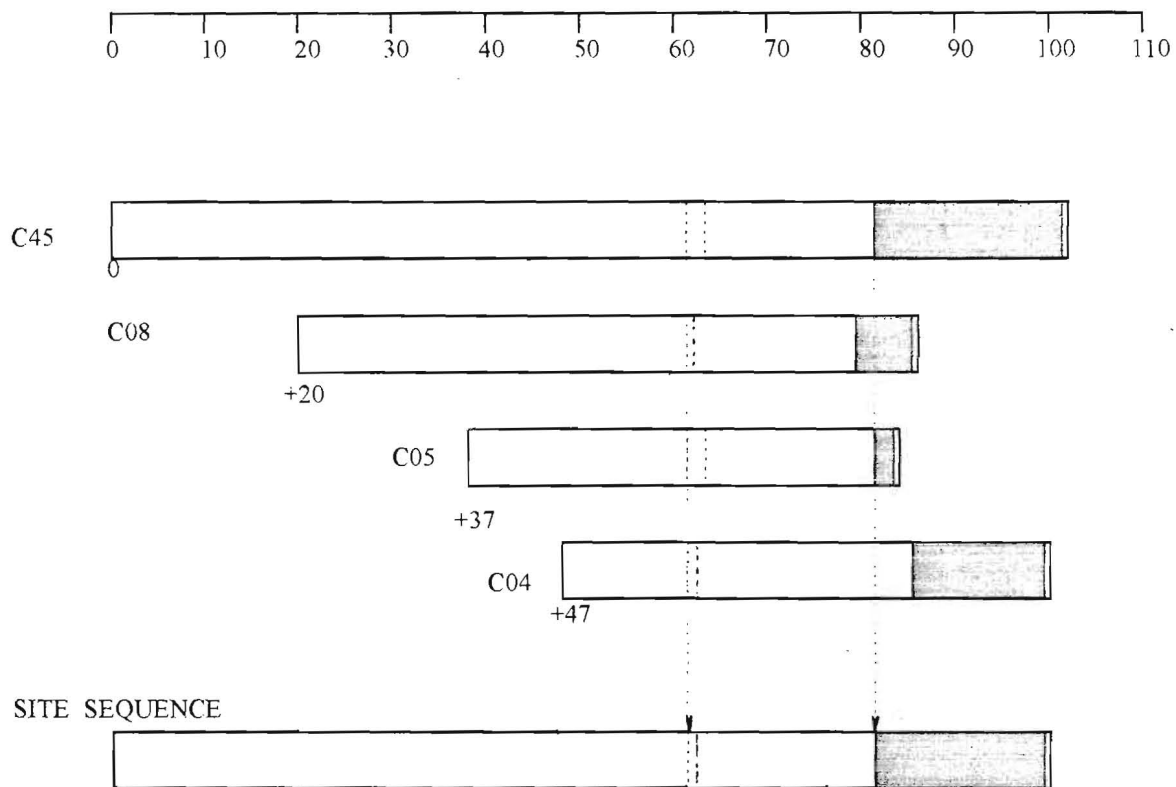


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

Even if all the sapwood rings are missing on all the timbers sampled, an estimate of the felling date is still possible in certain cases. For provided the original last heartwood ring of the tree, called the heartwood/sapwood boundary (H/S), is still on some of the samples, an estimate for the felling date of the group of trees can be obtained by adding on the full 25 years, or 15 to 40 for the range of felling dates.

If none of the timbers have their heartwood/sapwood boundaries, then only a *post quem* date for felling is possible.

5. **Estimating the Date of Construction.** There is a considerable body of evidence in the data collected by the Laboratory that the oak timbers used in vernacular buildings, at least, were used 'green' (see also Rackham (1976)). Hence provided the samples are taken *in situ*, and several dated with the same estimated common felling date, then this felling date will give an estimated date for the construction of the building, or for the phase of construction. If for some reason or other we are rather restricted in what samples we can take, then an estimated common felling date may not be such a precise estimate of the date of construction. More sampling may be needed 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 Fig 6 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 Fig 6. 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 1988b, 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* 1988a). 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 (1988b) and is illustrated in the graphs in Fig 7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence (a), the generally large early growth after 1810 is very apparent as is the smaller generally later growth from about 1900 onwards. A similar difference can be observed in the lower sequence 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, hopefully corresponding to good and poor growing seasons, respectively. The two corresponding sequences of Baillie-Pilcher indices are plotted in (b) where the differences in the early and late growths have been removed and only the rapidly changing peaks and troughs remain only associated with the common climatic signal and so make cross-matching easier.

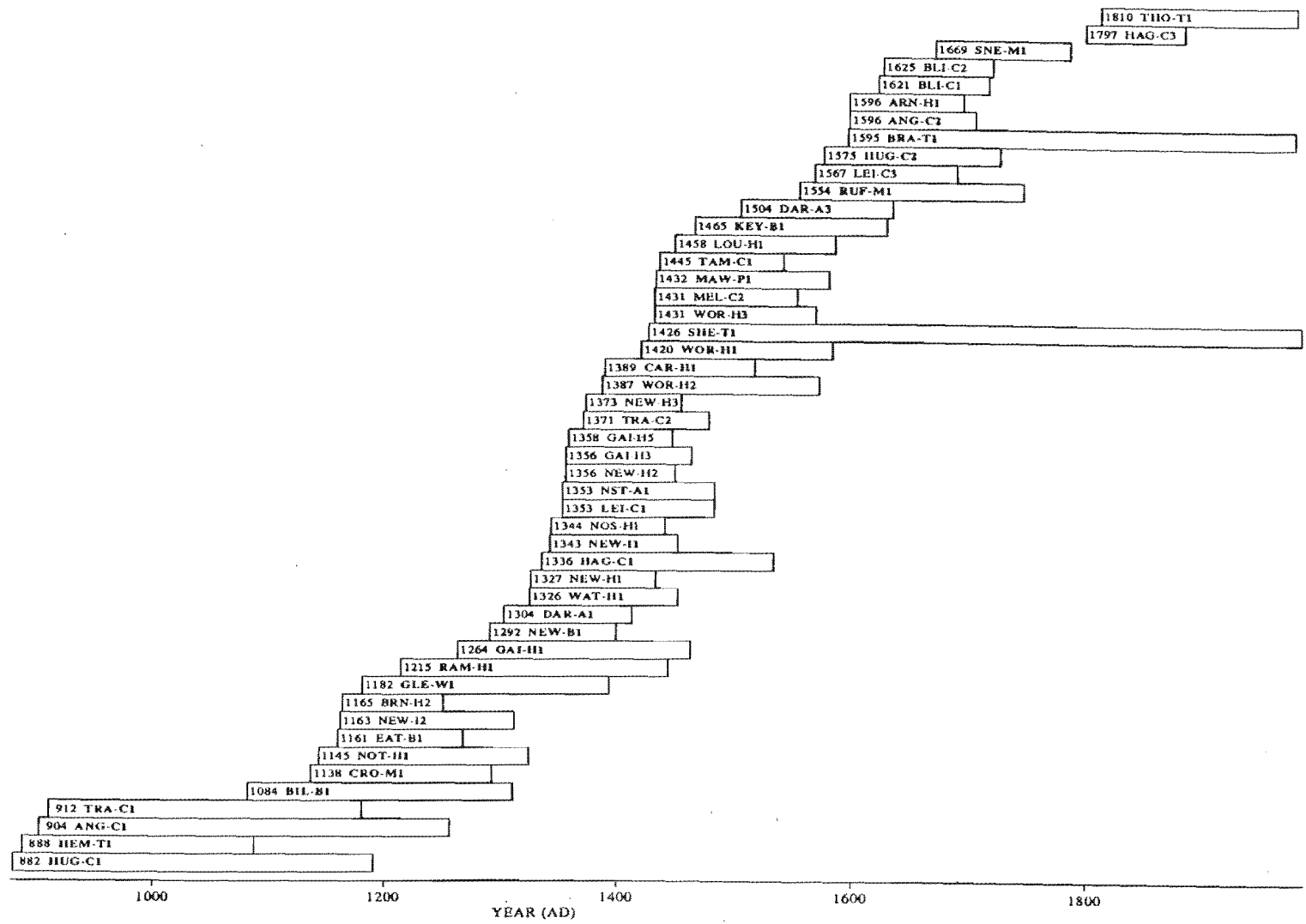


Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

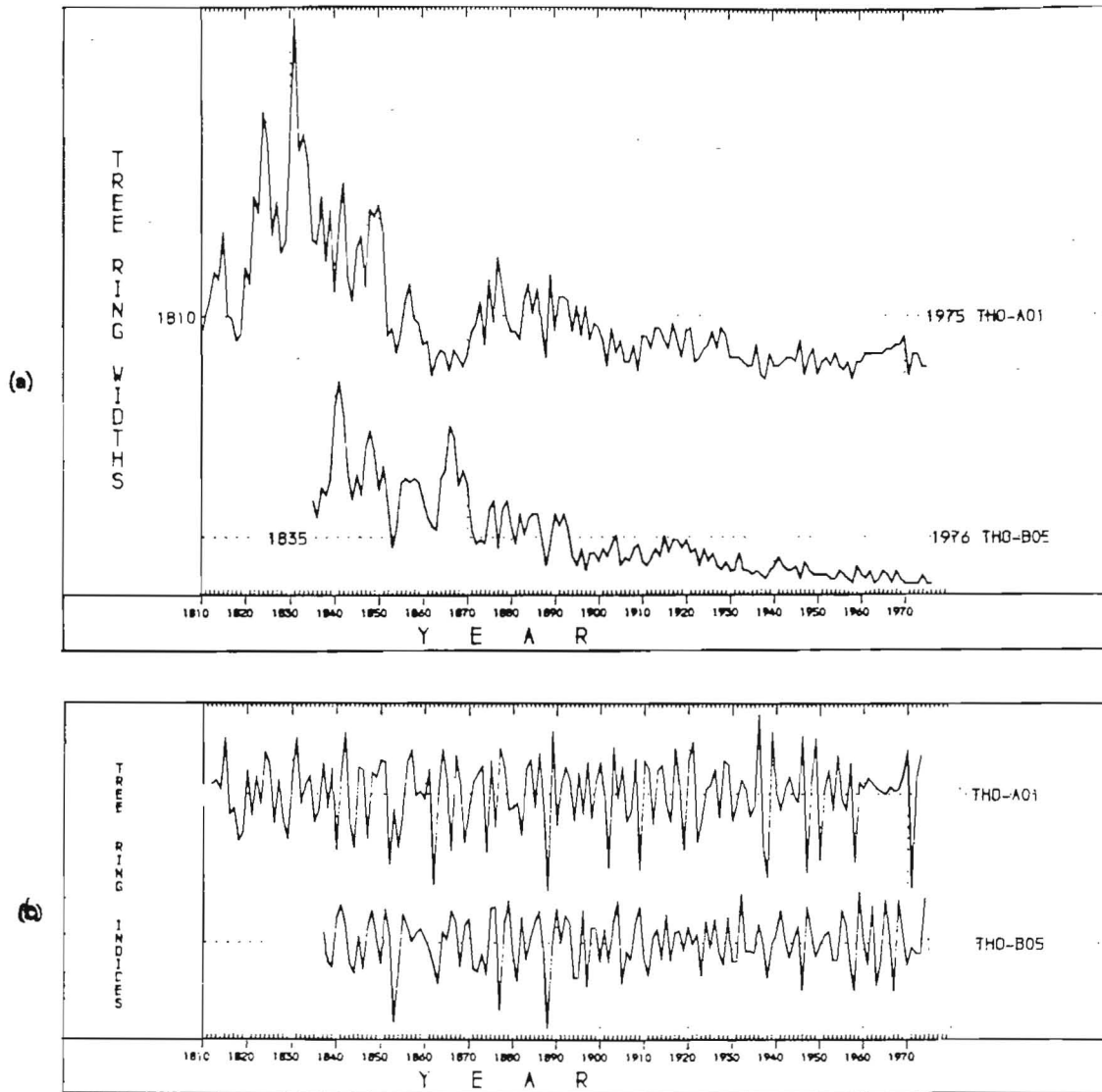


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences.

(b) The *Baillie-Pilcher indices* of the above widths. The growth-trends have been removed completely.

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