

Centre for Archaeology Report 84/2003

**Tree-Ring Analysis of Timbers from Hulme Hall, Allostock,
Near Northwich, Cheshire**

A J Arnold, R E Howard and Dr C D Litton

© English Heritage 2003

ISSN 1473-9224

The Centre for Archaeology Report Series incorporates the former Ancient Monuments Laboratory Report Series. Copies of Ancient Monuments Laboratory Reports will continue to be available from the Centre for Archaeology (see back cover for details).

**TREE-RING ANALYSIS OF TIMBERS FROM
HULME HALL,
ALLOSTOCK,
NEAR NORTHWICH,
CHESHIRE**

**A J ARNOLD
R E HOWARD
DR C D LITTON**

Summary

Eighty-one core samples were obtained from a wide range of locations at this site. Analysis of these produced four site chronologies of fifteen, seven, three, and two samples, each of overall lengths 116, 101, 68, and 119 rings respectively. Only the first two of these, site chronologies ALSASQ01 and ALSASQ02, could be dated, these spanning the years AD 1574 to AD 1689, and AD 1510 to AD 1610, respectively.

Interpretation of the sapwood on the dated samples indicates that much of the material, particularly timbers from Floor S1, Roof S1/S2, Roof S3/S4, and a single timber from Floor S3, have an estimated felling date in the range AD 1699 - 1724. It is likely that such a felling date relates to the suspected late seventeenth-century remodelling.

However, there is some slightly earlier material with some further timbers from Floor S3 having an estimated felling date in the range AD 1590 - 1615. Timbers from Floor F6 appear to be possibly of two felling dates, one estimated as AD 1605 - 30, the other estimated as AD 1625 - 50.

There is no confirmed tree-ring evidence for any earlier material in any other part of the building, either original or reused.

**TREE-RING ANALYSIS OF TIMBERS FROM
HULME HALL,
ALLOSTOCK,
NEAR NORTHWICH,
CHESHIRE**

**A J ARNOLD
R E HOWARD
DR C D LITTON**

Tree-Ring Analysis of Timbers from Hulme Hall, Allostock, Near Northwich, Cheshire

A J Arnold, R E Howard and Dr C D Litton

Summary

Eighty-one core samples were obtained from a wide range of locations at this site. Analysis of these produced four site chronologies of fifteen, seven, three, and two samples, each of overall lengths 116, 101, 68, and 119 rings respectively. Only the first two of these, site chronologies ALSASQ01 and ALSASQ02, could be dated, these spanning the years AD 1574 to AD 1689, and AD 1510 to AD 1610, respectively.

Interpretation of the sapwood on the dated samples indicates that much of the material, particularly timbers from Floor S1, Roof S1/S2, Roof S3/S4, and a single timber from Floor S3, have an estimated felling date in the range AD 1699 - 1724. It is likely that such a felling date relates to the suspected late seventeenth-century remodelling.

However, there is some slightly earlier material with some further timbers from Floor S3 having an estimated felling date in the range AD 1590 - 1615. Timbers from Floor F6 appear to be possibly of two felling dates, one estimated as AD 1605 - 30, the other estimated as AD 1625 - 50.

There is no confirmed tree-ring evidence for any earlier material in any other part of the building, either original or reused.

Keywords

Dendrochronology
Standing Building

Author's address

University of Nottingham, University Park, Nottingham, NG7 2RD

Many CfA reports are interim reports which make available the results of specialist investigations in advance of full publication. They are not subject to external refereeing, and their conclusions may sometimes have to be modified in the light of archaeological information that was not available at the time of the investigation. Readers are therefore advised to consult the author before citing the report in any publication and to consult the final excavation report when available.

Opinions expressed in CfA reports are those of the author and are not necessarily those of English Heritage.

Introduction

Hulme Hall is the decayed remnants of the medieval Manor of Hulme, standing on an isolated and remote moated spot about three miles north of Northwich (SJ 724724; Figure 1). The hall was originally the seat of the Grosvenor family who came over from Normandy with William the Conqueror. They were to become a prominent Cheshire family in the Middle Ages. The family already owned land in Allostock when Richard Grosvenor acquired the Manor of Hulme from Graham de Lostock in AD 1234, and from then until AD 1465 it was their principal residence.

In AD 1465 the Manor was inherited by one of the Grosvenor daughters, who married John Legh of Booths. Their son, also named John Legh, likewise died without a direct male heir and the Manor was inherited by his daughter, Elizabeth, who married Peter Shakerley of Shakerley in Lancashire. His son, Geoffrey Shakerley, appears to have made the Manor of Hulme his residence early in the sixteenth century and it remained the principal seat of the Shakerley family for the better part of two hundred years.

Geoffrey Shakerley's grandson, also named Geoffrey Shakerley, was Sheriff of Cheshire in the reign of James I, and the latter's great-grandson, Sir Geoffrey Shakerley, fought on the Royalist side in the Civil War and was governor of Chester Castle. From the late-seventeenth century onwards, although Hulme Hall remained in the possession of the Shakerley family, they appear to have lived elsewhere and the Hall was presumably tenanted. It is believed, on the basis of stylistic interpretation of various floor-frame beams, that substantial internal alterations were made to the buildings in the late-seventeenth century. In the nineteenth century much of the hall was demolished with that which remained being encased in brickwork. The site is still accessed across the medieval stone bridge

The building, an outline plan of which is given in Figure 2, now comprise three principal blocks, an east and a west block connected by a central block. It is believed that each of these three blocks contains fabric dating to the seventeenth-century alteration phase, with some of the timbers possibly being earlier. For example, while the roofs of the central and east blocks appear to be made entirely of softwood, that of the west block appears, on the basis of the form of the framing, to retain its original oak timbers. The frames of the first and second floors of each block also appear, again judged on stylistic evidence, to be made of later, probably seventeenth-century, oak. In addition there are two nineteenth-century single-storey extensions which, judging by the evidence of redundant mortices, reuse oak beams as purlins. It is believed that these may be from other parts of the early hall demolished in the nineteenth century. In general, the survey of the building undertaken by Anthony Blacklay and Associated indicates the possible use of timbers of different periods.

The building has suffered in the past from a lack of maintenance and periodic bouts of vandalism. It is currently (AD 2003) in poor condition and boarded-up. Proposed mineral extraction from the adjacent brinefields also affects the grounds around the building. The new owners of the site, Ineos Chlor are prepared to carry out urgent repairs and are keen to find a viable use of the building. As part of this process Ineos Chlor have commissioned a condition survey and a schedule of works.

The building is presently grade II* listed and is on the English Heritage Buildings at Risk Register.

Sampling

Sampling and analysis by tree-ring dating were commissioned by English Heritage, the purpose of this being to provide a precise date for a number of elements of the hall. In particular samples were to be obtained from what were believed might be original, possibly sixteenth-century, timbers of the east block roof; and from first- and second-floor frames of each of the three blocks. Samples were also to be obtained from timbers, possibly originally sixteenth-century, reused as purlins in two nineteenth-century extensions, plus samples from the timbers of the main stairs.

Given the complicated and multi-element nature of the site, helpful direction was obtained from Anthony Blacklay, of Anthony Blacklay & Associates, Architects & Historic Buildings and Landscape Consultants of Nantwich, as to the possible phasing of each part of the building. Thus, on the basis of this advice and from the extensive number of timbers available, a total of eighty-one samples was obtained. Each sample was given the code ALS-A (for Allostock, site "A") and numbered 01 - 81. Timbers were selected on the basis of their having sufficient rings for suitable analysis, and, where possible, for having sapwood, or at least the heartwood/sapwood boundary.

In this respect it was notable that while many of the roof timbers did retain some sapwood, it, and in some cases even the heartwood, was severely decayed, rotted, and soft. This was no doubt in large measure due to their long-time exposure to water leaking through the roofs. On the other hand the floor joists, which were more protected, had been severely trimmed by the original carpenters, with much of the sapwood being removed at that time.

An attempt was made to obtain samples evenly distributed between each element of the building. However, this was not always possible. In some cases this was due to there being insufficient oak timbers in one room, but the main reason for the lack of samples was that the timbers appeared to have too few rings, ie, less than 54, for satisfactory analysis. The most notable absence from sampling is the case of the timbers reused as purlins in the nineteenth-century extensions.

Where possible the approximate locations of timbers sampled were recorded at the time of coring on drawings kindly provided by Anthony Blackley and adapted to show the approximate positions of individual beams. Unfortunately the drawings do not show individual floor or roof timbers. These drawings are reproduced here as Figures 3a - c. In the architects plans each room has been numbered and prefixed with the letters "G" for ground floor, "F" for first floor, and "S" for second floor. This location system has been followed in Table 1 where details of the samples are given. In this Table timbers are numbered and identified on a north-to-south, or east-to-west basis as appropriate. In some cases, as with floor-frames, the presence of larger bridging beams has been used to divide the frames up into sections or sides, again described north / south / central, etc, as appropriate. Using the drawings and Table 1 it should be possible to identify the general location of timbers sampled.

The Laboratory would like to take this opportunity to thank Anthony Blacklay in particular for his invaluable help in deciphering the possible phasing of the building and for providing plans and drawings. We would also like to thank Peter Latham and Peter Downes of Ineos Chlor for their constant cooperation in accessing this difficult and dangerous building, and for their professional concern for site safety.

Analysis

Each of the eighty-one samples was prepared by sanding and polishing. At this point it was seen that one sample, ALS-A61, not only had very few rings, less than 30, but also had highly distorted rings and it was rejected. The widths of the annual growth-rings of the remaining eighty samples were then measured. The data of these measurements are given at the end of this report. The measured samples were then compared with each other by the Litton/Zainodin grouping procedure (see appendix).

Given that a large number of samples had only just at the Laboratories usual minimum number of rings for satisfactory analysis, ie 54, the allowed overlap between them was reduced to 40 rings. At a minimum value of $t=4.5$ four separate groups of cross-matching samples could be formed. The cross-matching samples of each group were then combined with each other at their relative offset positions to form site chronologies ALSASQ01 - ALSASQ04.

Each site chronology was then compared with the other three and with the remaining ungrouped samples. There was, however, no further satisfactory cross-matching. Each site chronology was then compared with a full range of reference chronologies for oak. This indicated a date for two site chronologies only, ALSASQ01 and ALSASQ02.

All the ungrouped samples were then compared individually with a full range of reference chronologies. There was, however, no further satisfactory cross-matching and these samples must, therefore, remain undated.

The relative positions of the cross-matching samples are shown in the bar diagrams Figures 4 - 6. Given that the two dated site chronologies overlap with each and include material from the same locations, the samples they contain are illustrated in a single bar diagram, Figure 4. The two component site chronologies are displayed by colour code with the samples sorted by location.

This analysis is summarised below:

Site chronology	Number of samples	Number of rings	Date span
ALSASQ01	15	116	AD 1574 - 1689
ALSASQ02	7	101	AD 1510 - 1610
ALSASQ03	3	68	Undated
ALSASQ04	2	119	Undated
Ungrouped	53	---	Undated

Interpretation

The relative positions of the heartwood/sapwood boundaries on the ten samples in site chronology ALSASQ01 where it exists is very consistent, varying by only nine years from relative position 170 (AD 1680) on samples ALS-A67, A68, and A69, to relative position 179 (AD 1689) on sample ALS-A49. Such consistency is indicative of timbers having a very similar, if not identical, felling date. The average heartwood/sapwood boundary date of the ten samples in site chronology ALSASQ01 where it exists is AD 1684. Using a 95% confidence limit for the amount of sapwood on mature oaks in this part of England of 15 - 40 rings would give the timbers represented by these samples an estimated felling date in the range AD 1699 to AD 1724.

The relative positions of the heartwood/sapwood boundaries of the four samples in site chronology ALSASQ02 where it exists is more variable, the difference between earliest and latest being 38 years. Such a variation suggests that timbers were felled at different times.

The earliest heartwood/sapwood boundaries are found on samples ALS-A72 and A73, at relative positions 62 and 67, AD 1572, and AD 1577, respectively. This is a variation of only five years and again may be indicative of a group of timbers having a single felling date. If this were assumed to be the case, the average last heartwood ring date of the two would be AD 1575. Using a 95% confidence limit for the amount of sapwood on mature oaks in this part of England of 15 - 40 rings would give the timbers represented by these samples an estimated felling date in the range AD 1590 to AD 1615.

The next heartwood/sapwood boundary in site chronology ALSASQ02 is found on sample ALS-A21, this being at relative position 80, AD 1590. Using the same confidence limit for the amount of sapwood as above would give the timber represented by this sample an estimated felling date in the range AD 1605 to AD 1630.

The latest heartwood/sapwood boundary of any sample in site chronology ALSASQ02 is found at relative position 100 on sample ALS-A14, AD 1610. Using the same confidence limit for the amount of sapwood as above would give the timber represented by this sample an estimated felling date in the range AD 1625 to AD 1650.

Conclusions

Analysis by tree-ring dating has produced four site chronologies from the material obtained at Hulme Hall. Only two of these, site chronology ALSASQ01 comprising fifteen samples and being of combined overall length 116 rings, and site chronology ALSASQ02 comprising seven samples, of combined overall length 101 rings, are dated, spanning the years AD 1574 to AD 1689 and AD 1510 to AD 1610 respectively.

Interpretation of the sapwood on the samples in site chronology ALASQ01 indicates that many of the dated timbers were cut in a single phase of felling estimated to have taken place sometime between AD 1699 - AD 1724. It will be noted from Table 1 and the bar diagram Figure 4 that much of this dated material is from the roof and floor-frames of rooms S1 - S4, suggesting that this area contains the greatest quantity of early eighteenth-century material.

Such a date is probably related to the believed seventeenth-century refurbishment phase, though on the basis of tree-ring dating, it is more likely to have taken place in the early eighteenth century. The tree-ring analysis shows no evidence at all of any earlier material from the central or western area of the building, either in its original position or reused.

Earlier phases of felling are, however, also present, being represented in site chronology ALASQ02. It is estimated, for example, that two timbers from Floor S3 (samples ALS-A72 and A73) have a felling date in the range AD 1590 to AD 1615. Additional felling dates within Floor F6 may also be represented in site chronology ALSASQ02. One timber, represented by sample ALS-A21, has an estimated felling date in the range AD 1605 to AD 1630. It is possible, however, that these three samples (ALS-A21, A72, and A73) were felled at the same time in the period AD 1605 to AD 1615, where the estimated felling date range of each overlap.

The other timber, represented by sample ALS-A14, has an estimated felling date in the range AD 1625 to AD 1650. Again, though, given that there is a slight overlap in the felling date ranges of these last two samples (ALS-A14 and A21), it is possible that they share a felling date in the range AD 1625 - 30.

It would thus appear that, as suspected during the survey of the building by Anthony Blacklay, timbers of different dates and possibly from different sources appear to have been used.

The measured samples from some fifty-three other timbers, an extremely high proportion, cannot be dated, despite every effort to do so. The most likely reason for this is the low number of annual rings on several of the cores. The majority of undated samples have only 54 rings, the minimum number for satisfactory analysis. A number of others undated samples have only 55 - 60 rings. Only ten undated samples have more than 60 rings. The low numbers of rings on the samples make satisfactory cross-matching, and the reliable dating of individual samples, very difficult if not impossible.

A number of the undated samples also show bands of narrow or distorted rings. These bands may be caused by stress, or some non-climatic influence such as pollarding or the stripping of leaves. This would have the effect of making the growth pattern of the samples incomparable with the reference patterns.

A further possible contributory factor in the lack of dating may be the widespread use of timbers with various felling dates in the sixteenth and seventeenth centuries, and possibly from different sources. Tree-ring dating tends to be more effective where groups of homogeneous timbers are sampled. In this instance the timbers may be too varied for complete success.

Bibliography

- Baillie, M G L, and Pilcher, J R, 1982 unpubl A master tree-ring chronology for England, unpubl computer file *MGB-EOI*, Queens Univ, Belfast
- Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1991 List 38 no 5 - Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, **22**, 40 – 3
- Howard, R E, Laxton, R R, Litton, C D, Morrison A, Sewell, J, and Hook, R, 1993 List 49 no 2 - Nottingham University Tree-Ring Dating Laboratory: Derbyshire, Peak Park and RCHME dendrochronological Survey 1991 - 92, *Vernacular Architect*, **24**, 43 – 4
- Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1994 List 57 no 10a - Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, **25**, 36 – 40
- Howard, R E, Laxton, R R, Litton, C D, Morrison A, Sewell, J, and Hook, R, 1996 List 66 no 8b - Nottingham University Tree-Ring Dating Laboratory: Derbyshire, Peak Park and RCHME dendrochronological Survey 1995 - 96, *Vernacular Architect*, **27**, 81 – 4
- Howard, R E, Laxton, R R, and Litton, C D, 1998 unpubl Dovebridge, Derbyshire, unpubl computer file *DOVBSQ01* (Nottingham University Tree-Ring Dating Laboratory)
- Howard, R E, Laxton, R R, and Litton, C D, 1999 *Tree-ring analysis of timbers from Bretby Hall, Bretby, Derbyshire*, Anc Mon Lab Rep, **43/99**
- Howard, R E, Laxton, R R, and Litton, C D, forthcoming *Tree-ring analysis of timbers from the Riding School, Bolsover Castle, Bolsover, Derbyshire*, Centre for Archaeol Rep
- Laxton, R R, and Litton, C D, 1988 An East Midlands master tree-ring chronology and its use for dating vernacular buildings, University of Nottingham, Dept of Classical and Archaeol Studies, Monograph Series, **III**
- Siebenlist-Kerner, V, 1978 Chronology, 1341-1636, for hillside oaks from Western England and Wales, in *Dendrochronology in Europe* (ed J M Fletcher), BAR Int Ser, **51**, 295-301
- Tyers, I, 1997 *Tree-ring Analysis of Timbers from Sinai Park, Staffordshire*, Anc Mon Lab Rep, **80/97**
- Tyers, I, and Groves C, 1999 unpubl England London, unpubl computer file *LON1175*, Sheffield Univ

Table 1: Details of samples from Hulme Hall, Allostock, Cheshire

Sample no	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
Floor-frame to room F5						
ALS-A01	Main north – south beam	71	h/s	-----	-----	-----
ALS-A02	West joist 7	54	h/s	-----	-----	-----
ALS-A03	West joist 2	55	no h/s	-----	-----	-----
ALS-A04	East joist 11	54	no h/s	-----	-----	-----
ALS-A05	West common rafter 3	69	h/s	-----	-----	-----
ALS-A06	East common rafter 10	54	h/s	-----	-----	-----
ALS-A07	East common rafter 12	55	h/s	-----	-----	-----
Floor-frame to room F4						
ALS-A08	Joist 4	56	h/s	-----	-----	-----
ALS-A09	Joist 1	55	h/s	-----	-----	-----
ALS-A10	Joist 3	54	h/s	-----	-----	-----
ALS-A11	Joist 5	57	h/s	-----	-----	-----
ALS-A12	Joist 2	56	h/s	-----	-----	-----
Floor-frame to room F6						
ALS-A13	Main east-west beam	58	h/s	-----	-----	-----
ALS-A14	Northern cross-beam	68	h/s	AD 1543	AD 1610	AD 1610
ALS-A15	South joist 2	54	no h/s	-----	-----	-----
ALS-A16	North joist 8	54	no h/s	-----	-----	-----
ALS-A17	South joist 4	60	h/s	-----	-----	-----

Table 1: continued

Sample no	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
Floor-frame to room F6 continued						
ALS-A18	North joist 9	55	no h/s	AD 1546	-----	AD 1600
ALS-A19	South joist 6	59	no h/s	AD 1510	-----	AD 1568
ALS-A20	North joist 10	70	no h/s	AD 1513	-----	AD 1582
ALS-A21	South joist 3	67	h/s	AD 1524	AD 1590	AD 1590
ALS-A22	South joist 5	55	h/s	-----	-----	-----
Floor-frame to room F3						
ALS-A23	East joist 3	70	h/s	-----	-----	-----
ALS-A24	East joist 4	56	h/s	-----	-----	-----
ALS-A25	West joist 6	54	h/s	-----	-----	-----
ALS-A26	West joist 2	57	h/s	-----	-----	-----
ALS-A27	West joist 5	65	h/s	-----	-----	-----
ALS-A28	East joist 2	58	h/s	-----	-----	-----
ALS-A29	Common joist 2 from east side	87	h/s	-----	-----	-----
ALS-A30	Western north -south bridging beam	54	h/s	-----	-----	-----
ALS-A31	North wall plate at east side	57	h/s	-----	-----	-----
ALS-A32	Joist 3 east side, mid section	56	3	-----	-----	-----
ALS-A33	Joist 2, east side, mid section	54	h/s	-----	-----	-----
ALS-A34	Joist 5, east side, south section	54	h/s	-----	-----	-----

Table 1: continued

Sample no	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
Floor-frame to room F1						
ALS-A35	Joist 1, east side	57	h/s	-----	-----	-----
ALS-A36	Joist 3, west side	57	h/s	-----	-----	-----
ALS-A37	Joist 2, mid section	54	h/s	-----	-----	-----
ALS-A38	Joist 4, west side	55	h/s	-----	-----	-----
ALS-A39	Joist 1, west side	59	h/s	-----	-----	-----
ALS-A40	Joist 5, east side	54	h/s	-----	-----	-----
Roof to room S3 / S4						
ALS-A41	East upper purlin, S3	54	h/s	-----	-----	-----
ALS-A42	Ridge beam (S3 - S4)	58	h/s	-----	-----	-----
ALS-A43	East middle purlin, S3	69	no h/s	AD 1594	-----	AD 1662
ALS-A44	West upper purlin, S4	60	h/s	-----	-----	-----
ALS-A45	East common rafter 7, S3	54	h/s	-----	-----	-----
ALS-A46	West middle purlin, S4	54	h/s	-----	-----	-----
ALS-A47	East lower purlin, S3	82	h/s	AD 1605	AD 1686	AD 1686
ALS-A48	West lower purlin, S4	54	h/s	-----	-----	-----
ALS-A49	East lower purlin, S2	75	h/s	AD 1615	AD 1689	AD 1689
Roof to room S1 / S2						
ALS-A50	West lower purlin, S1	103	no h/s	AD 1574	-----	AD 1676
ALS-A51	West middle purlin, S2	55	h/s	-----	-----	-----

Table 1: continued

Sample no	Sample location	Total Rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
Roof to room S1 / S2 continued						
ALS-A52	East middle purlin, S2	76	h/s	AD 1613	AD 1688	AD 1688
ALS-A53	East upper purlin, S2	54	h/s	-----	-----	-----
ALS-A54	Ridge beam, S1 / S2	55	h/s	-----	-----	-----
ALS-A55	West middle purlin, S1	54	h/s	-----	-----	-----
ALS-A56	East common rafter 9, S2	56	h/s	-----	-----	-----
ALS-A57	West upper purlin, S1	98	h/s	AD 1585	AD 1682	AD 1682
ALS-A58	East common rafter 10, S2	66	h/s	AD 1619	AD 1684	AD 1684
ALS-A59	West common rafter 7, S1	86	no h/s	AD 1582	-----	AD 1667
ALS-A60	East common rafter 7, S2	57	h/s	-----	-----	-----
ALS-A61	West common rafter 2, S1	nm	h/s	-----	-----	-----
Floor-frame to room S1						
ALS-A62	Joist 8, centre section	55	h/s	-----	-----	-----
ALS-A63	Joist 6, west section	54	h/s	-----	-----	-----
ALS-A64	Joist 7, centre section	55	no h/s	AD 1588	-----	AD 1642
ALS-A65	Joist 6, centre section	54	h/s	-----	-----	-----
ALS-A66	N-S beam, west section	69	h/s	AD 1616	AD 1684	AD 1684
ALS-A67	Joist 2, west section	54	h/s	AD 1627	AD 1680	AD 1680
ALS-A68	N-S beam, east section	90	h/s	AD 1591	AD 1680	AD 1680
ALS-A69	Joist 3, east section	54	h/s	-----	-----	-----
ALS-A70	Joist 7, west section	61	h/s	AD 1620	AD 1680	AD 1680
ALS-A71	Joist 5, east section	55	h/s	AD 1630	AD 1684	AD 1684

Table 1: continued

Sample no	Sample location	Total Rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
Floor-frame to room S3						
ALS-A72	Joist 2, east side	54	h/s	AD 1519	AD 1572	AD 1572
ALS-A73	Joist 4, east side	47	h/s	AD 1531	AD 1577	AD 1577
ALS-A74	Central north – south beam	57	h/s	-----	-----	-----
ALS-A75	Joist 6, east side	92	h/s	-----	-----	-----
ALS-A76	Joist 5, west side	88	no h/s	AD 1585	-----	AD 1672
Stair timbers						
ALS-A77	Rail beneath stairs, ground floor	56	h/s	-----	-----	-----
ALS-A78	Top newel post, first floor	54	h/s	-----	-----	-----
ALS-A79	Middle rail to stair, first floor	62	h/s	-----	-----	-----
ALS-A80	Middle newel post (lower part)	55	h/s	-----	-----	-----
ALS-A81	Middle newel post (upper part)	84	h/s	-----	-----	-----

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

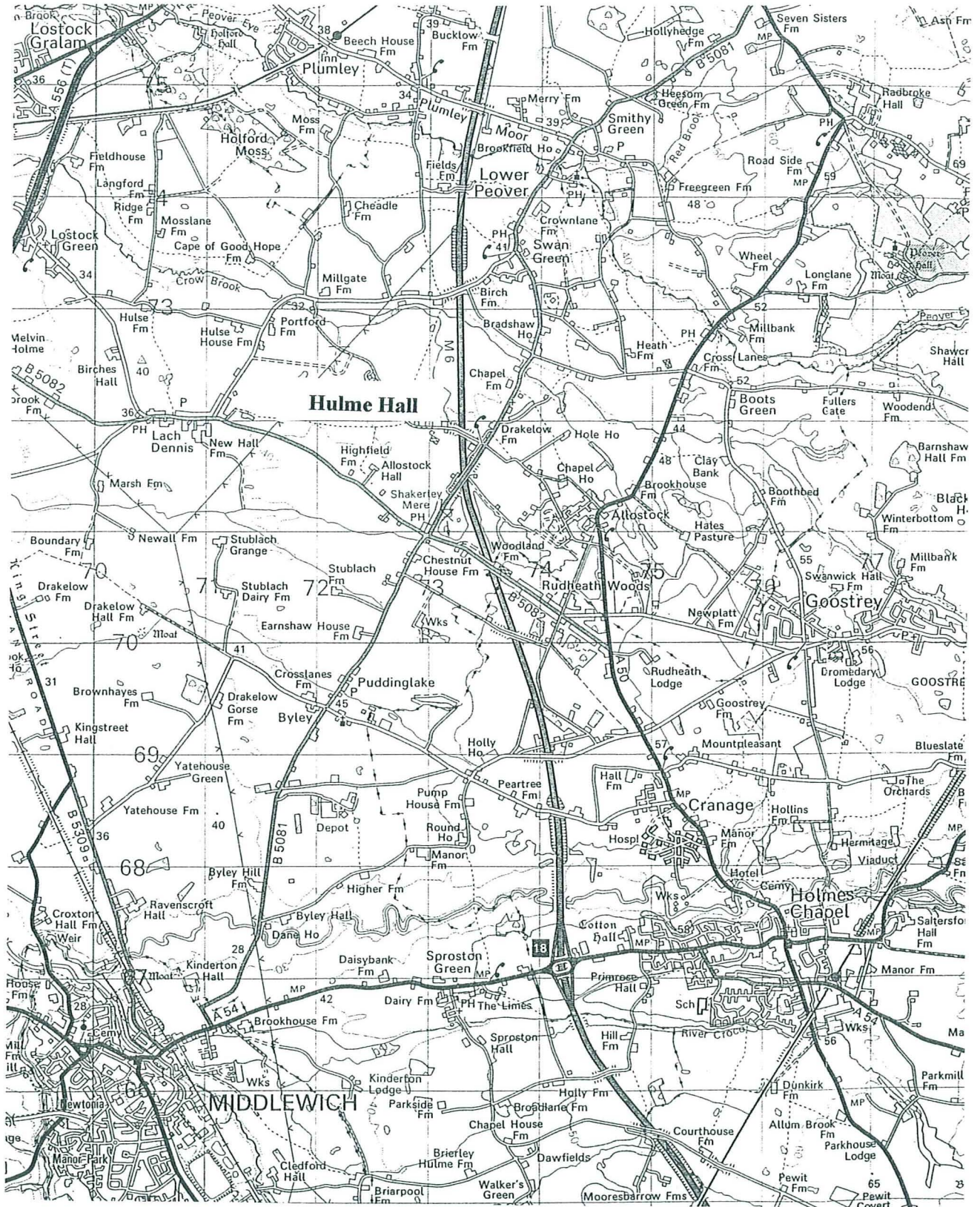
Table 2: Results of the cross-matching site chronology ALSASQ01 and relevant reference chronologies when the date of the first ring is AD 1574 and its last ring date is AD 1689

Reference chronology	Span of chronology	<i>t</i> -value	
Bolsover Castle, Derby (Riding house)	AD 1494 – 1744	8.9	(Howard <i>et al</i> forthcoming)
Bretby Hall, Bretby, Derbys	AD 1494 – 1718	6.7	(Howard <i>et al</i> 1999)
England	AD 401 – 1981	6.4	(Baillie and Pilcher 1982 unpubl)
East Midlands	AD 882 – 1981	6.4	(Laxton and Litton 1988)
Blidworth Church, Blidworth, Notts	AD 1621 – 1713	6.1	(Laxton and Litton 1988)
England London	AD 413 – 1728	5.9	(Tyers and Groves 1999 unpubl)
Sinai Park, Staffs	AD 1227 – 1750	5.7	(Tyers 1997)
Brewhouse Yard, Nottingham	AD 1544 – 1701	5.2	(Howard <i>et al</i> 1994)

Table 3: Results of the cross-matching site chronology ALSASQ02 and relevant reference chronologies when the date of the first ring is AD 1510 and its last ring date is AD 1610

Reference chronology	Span of chronology	<i>t</i> -value	
Dovebridge, Derbys	AD 1502 – 1617	6.1	(Howard <i>et al</i> 1998 unpubl)
Keyworth Barn, Keyworth, Notts	AD 1451 – 1528	5.4	(Laxton and Litton 1988)
East Midlands	AD 882 – 1981	5.3	(Laxton and Litton 1988)
Long Clawson, Leics	AD 1485 – 1602	5.3	(Howard <i>et al</i> 1991)
Hallfield House, Bradfield, S Yorks	AD 1482 – 1592	5.2	(Howard <i>et al</i> 1996)
England	AD 401 – 1981	5.2	(Baillie and Pilcher 1982 unpubl)
Frith Hall, Brampton, Derbys	AD 1480 – 1602	5.1	(Howard <i>et al</i> 1993)
Wales and West Midlands	AD 1341 – 1538	4.8	(Siebenlist-Kerner 1978)

Figure 1: Map to show general location of Hulme Hall



© Crown Copyright
and database right
2013. All rights
reserved. Ordnance
Survey Licence
number 100024900

Figure 2: General layout of Hulme Hall based on ground floor plan

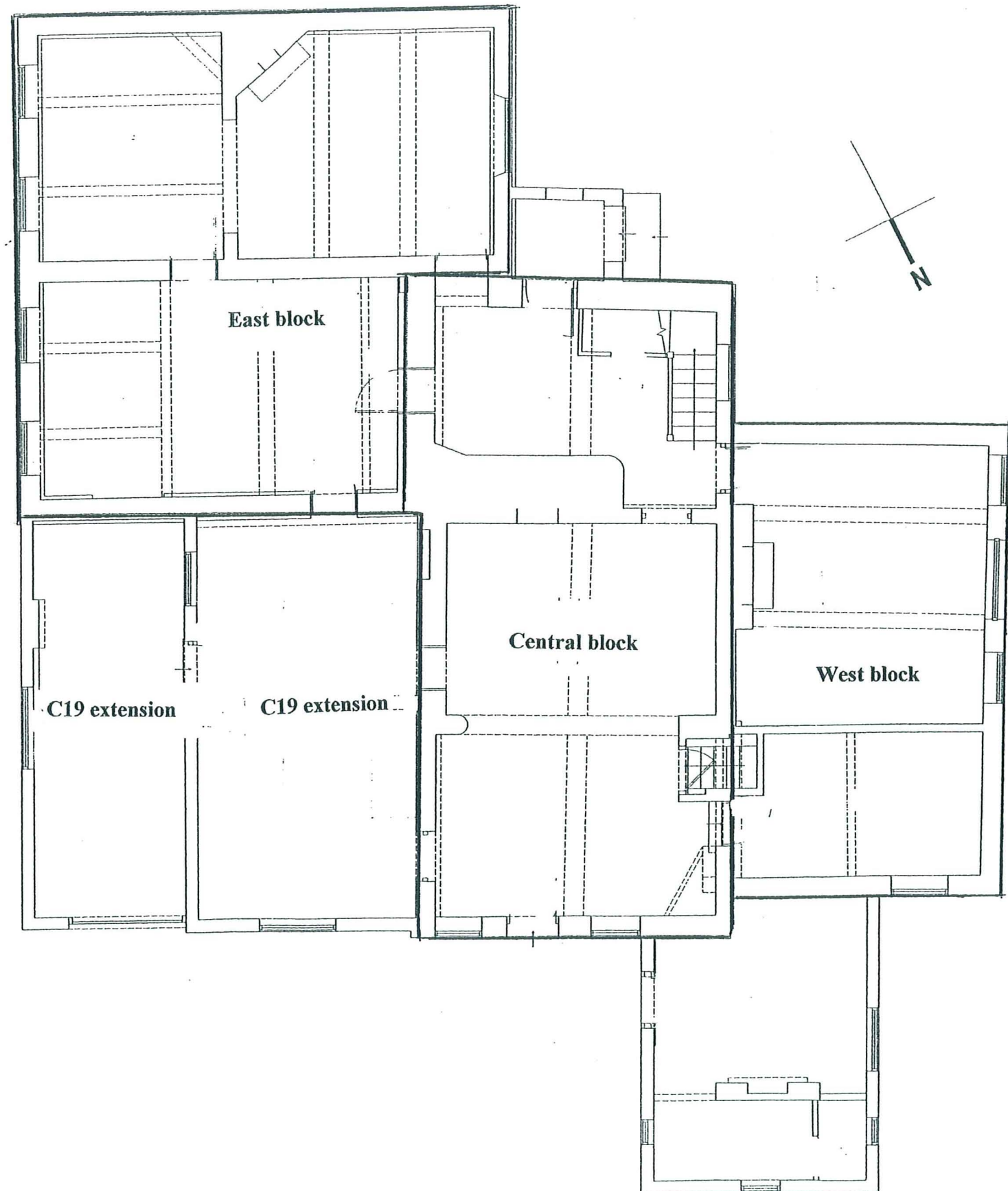


Figure 3a: Plan to show approximate location of sampled timbers based on a first-floor plan

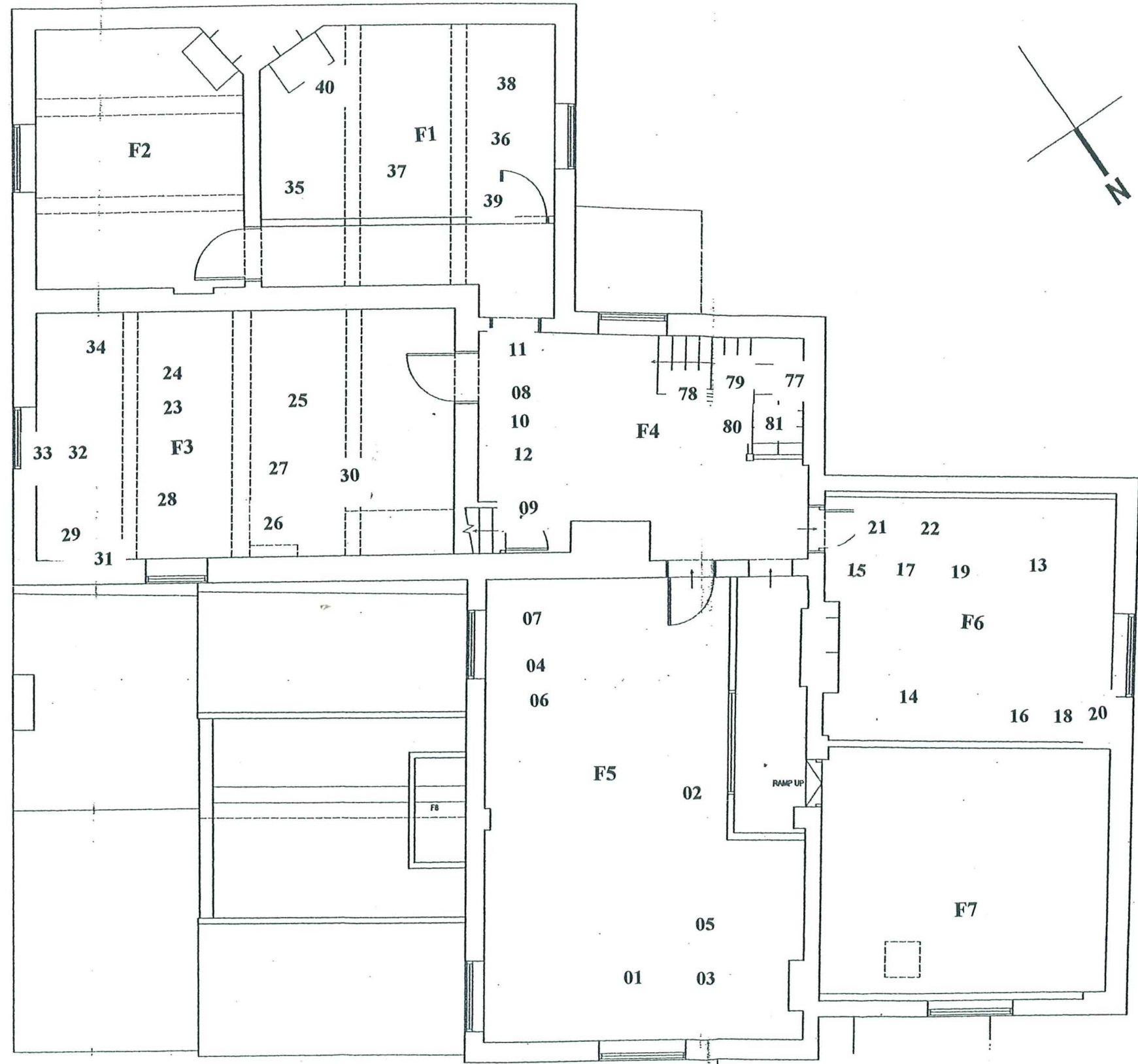


Figure 3b: Plan to show approximate location of sampled timbers based on a second-floor plan

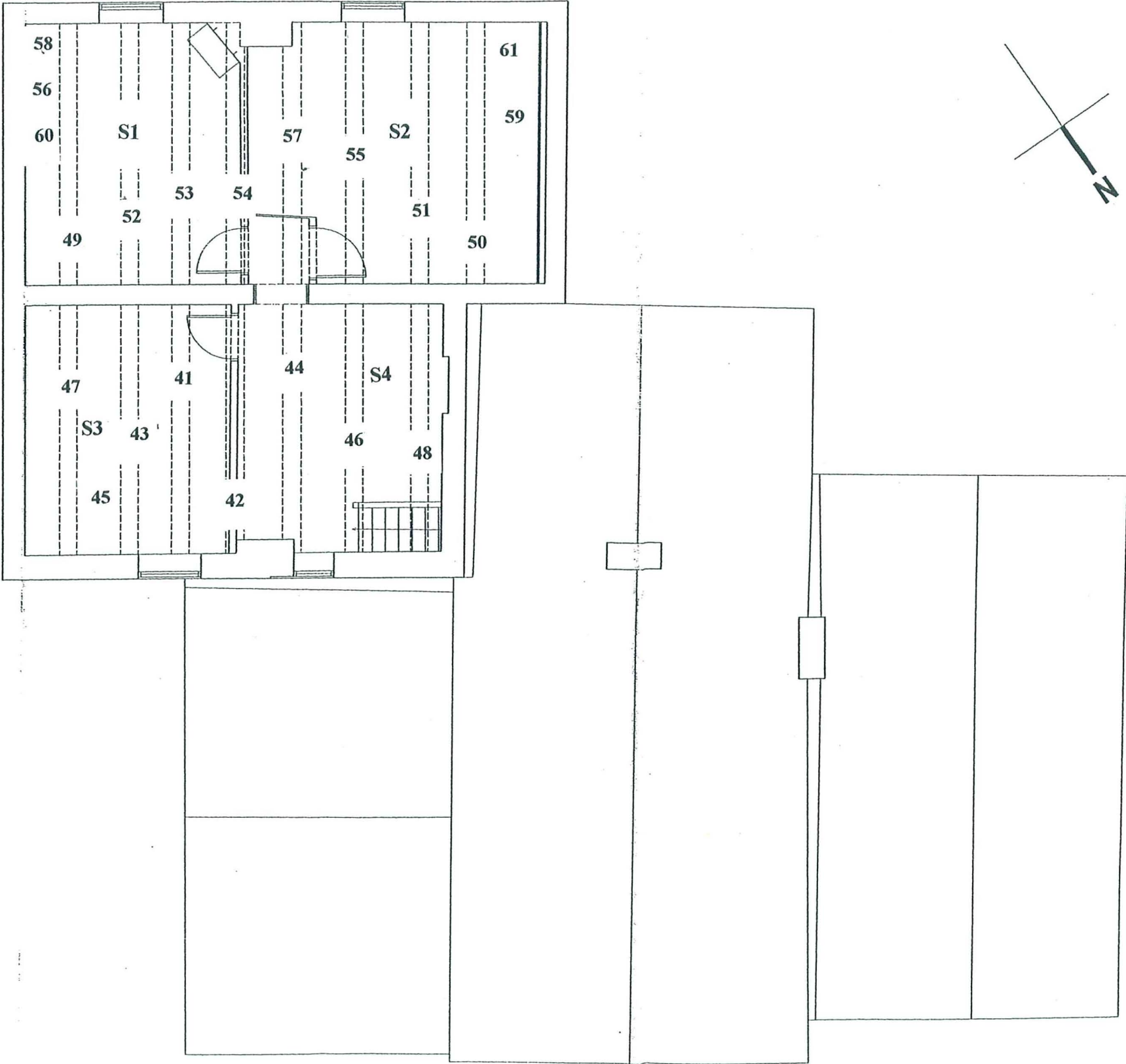


Figure 3c: Plan to show approximate location of sampled timbers based on a second-floor plan

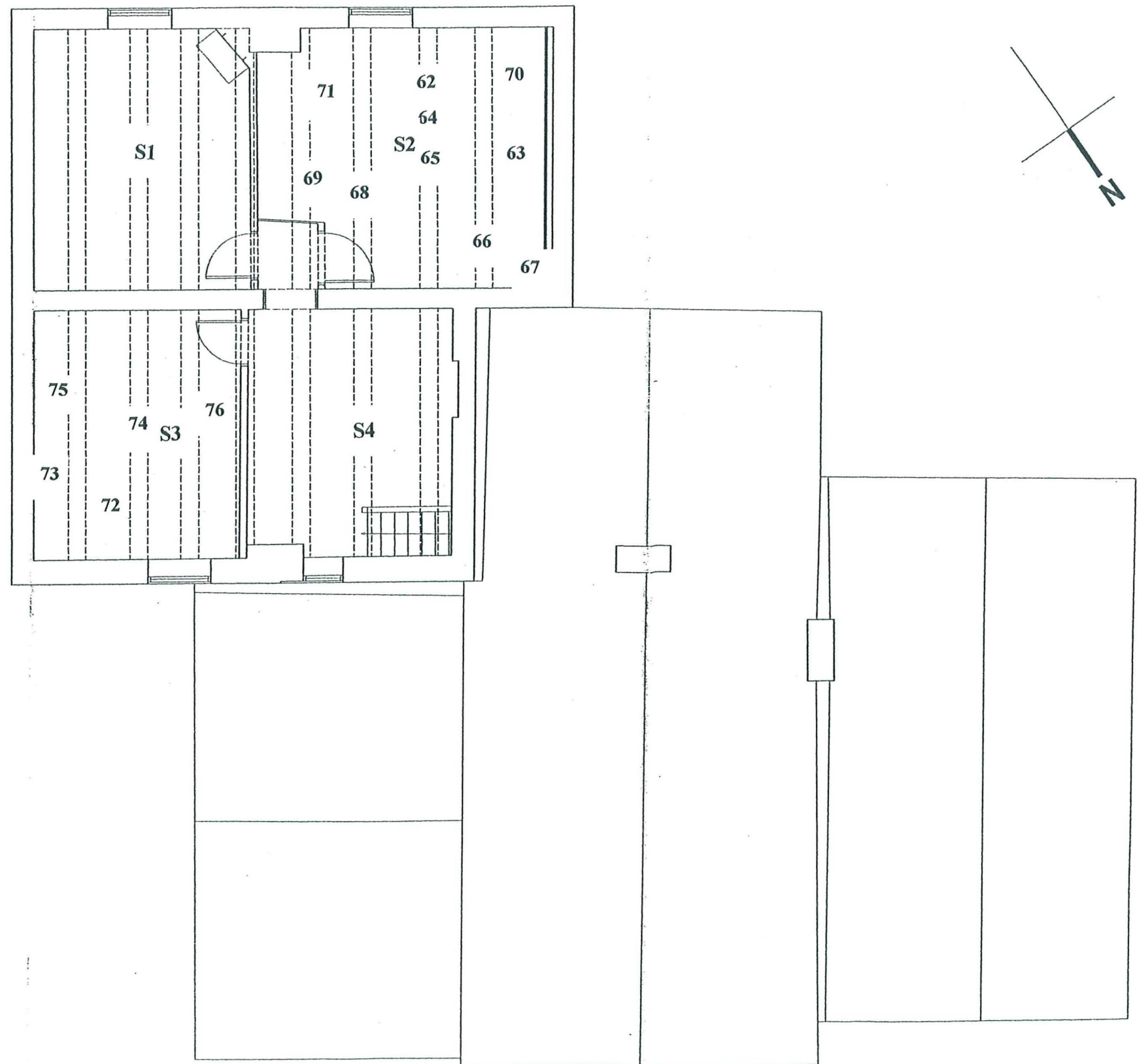
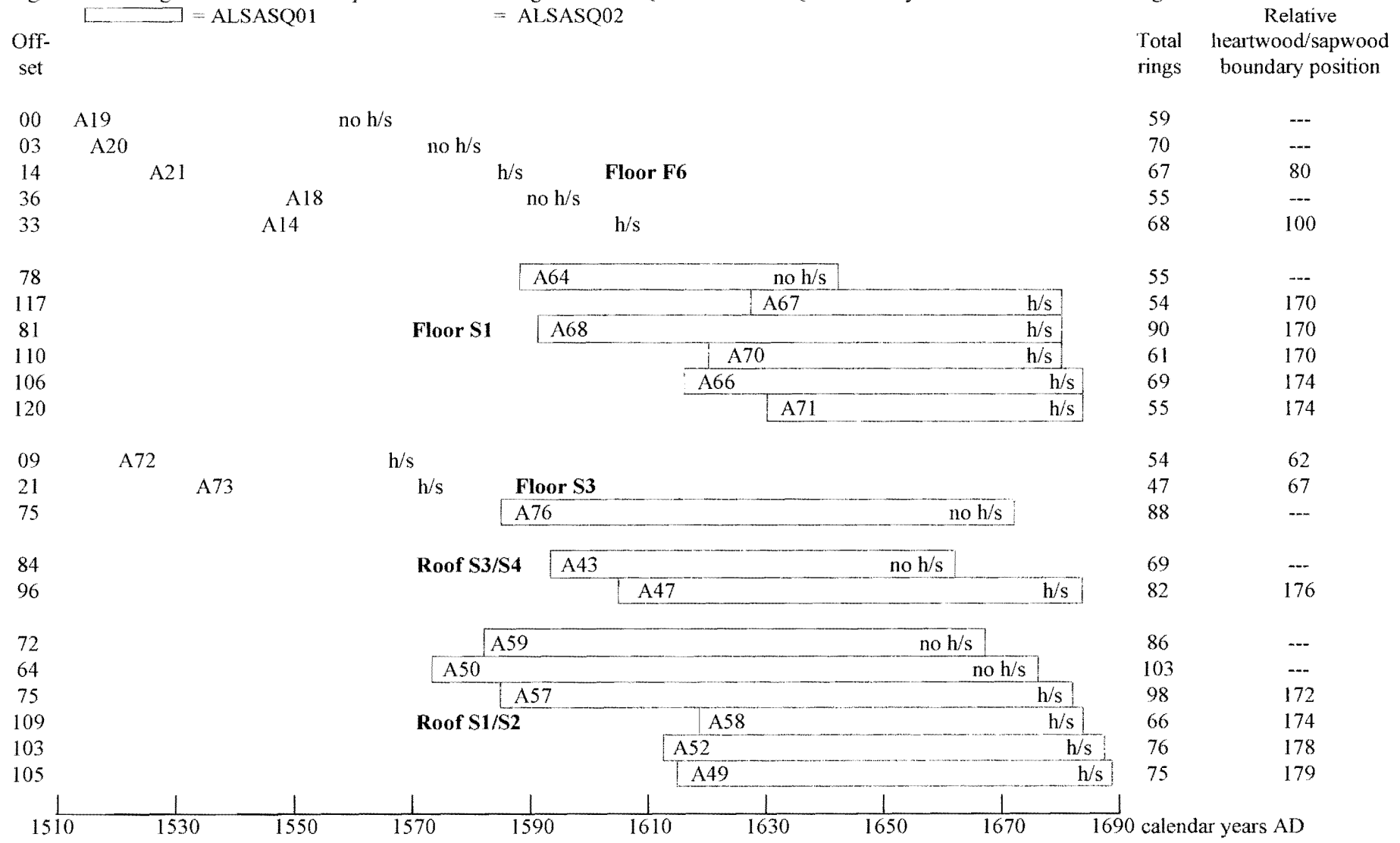


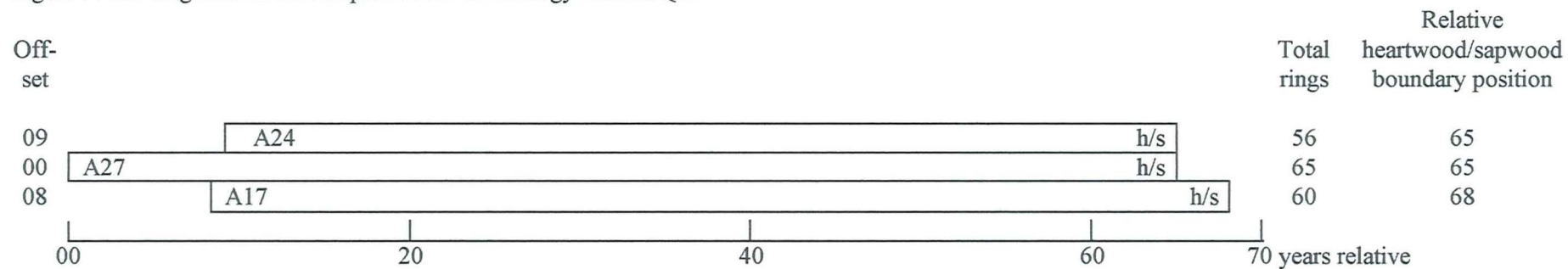
Figure 4: Bar diagram of all dated samples in site chronologies ALSASQ01 and ALSASQ02 sorted by location in relative last ring order



17

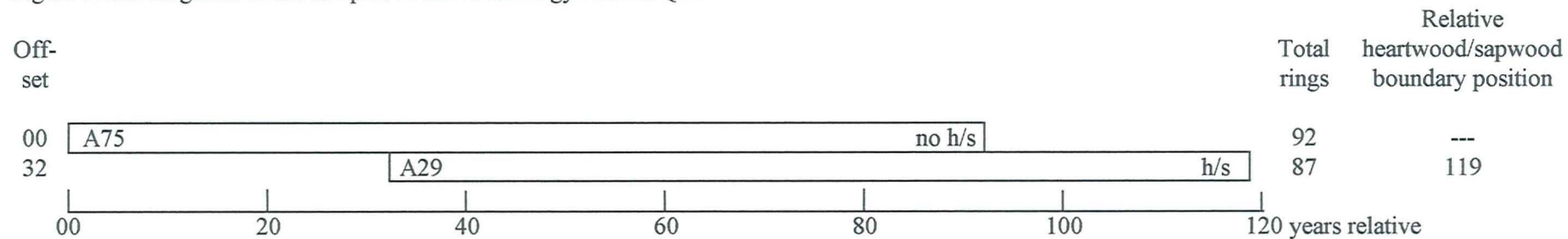
white bars = heartwood rings
 h/s = heartwood/sapwood boundary is last ring on sample

Figure 5: Bar diagrams of the samples in site chronology ALSASQ03



18

Figure 6: Bar diagrams of the samples in site chronology ALSASQ04



white bars = heartwood rings
 h/s = heartwood/sapwood boundary is last ring on sample

Data of measured samples – measurements in 0,01 mm units

ALS-A01A 71

324 518 466 420 300 393 562 524 507 523 317 441 488 459 409 516 458 449 380 305
341 380 359 419 322 268 156 242 301 292 294 261 182 249 218 190 227 193 293 243
226 240 216 268 251 280 202 219 183 217 207 209 181 181 166 219 206 168 166 188
249 239 251 200 230 138 131 169 149 163 185

ALS-A01B 71

373 556 423 348 301 395 555 538 509 519 320 449 492 457 407 505 482 444 386 304
336 383 366 405 323 266 170 244 298 296 290 248 183 219 210 171 223 190 276 249
227 219 258 264 227 305 184 246 197 183 220 217 176 181 162 231 199 177 168 174
227 232 246 204 206 158 128 172 152 175 146

ALS-A02A 54

253 323 295 722 371 296 540 439 456 493 517 540 358 404 414 449 354 402 506 374
347 501 635 460 463 422 550 339 627 504 375 515 615 642 605 650 632 410 412 518
440 495 437 586 284 387 384 330 348 295 360 327 331 259

ALS-A02B 54

232 310 314 341 355 320 560 433 455 481 495 534 388 360 429 475 420 392 491 396
330 481 610 460 458 439 542 344 640 501 472 464 616 583 649 641 634 373 483 506
425 468 444 561 306 354 369 316 346 251 361 320 344 265

ALS-A03A 55

459 353 255 194 182 149 164 164 225 172 171 113 118 168 171 228 216 153 171 162
119 53 58 103 125 179 196 51 93 134 172 136 170 156 162 147 178 151 195 205
128 153 155 125 56 61 111 110 174 190 159 158 155 150 191

ALS-A03B 55

467 349 254 206 169 146 171 159 225 169 155 113 118 167 173 218 223 165 173 154
122 51 71 86 141 184 200 53 93 113 158 199 171 150 175 138 182 144 193 198
164 166 162 121 54 56 112 131 163 206 127 154 162 159 179

ALS-A04A 54

219 273 189 293 358 419 331 473 372 376 334 594 393 484 472 536 484 563 603 542
497 400 385 386 466 496 410 355 445 356 360 408 384 328 436 502 438 420 335 385
383 399 341 432 353 400 483 518 384 358 439 545 507 569

ALS-A04B 54

226 276 194 287 276 391 324 530 344 373 353 583 408 409 469 535 466 516 640 534
506 400 391 380 468 480 396 371 432 383 348 413 385 333 435 481 420 470 316 376
365 397 346 421 396 401 465 489 387 385 478 498 518 539

ALS-A05A 69

66 64 104 121 83 82 127 152 123 175 193 171 150 108 99 99 106 108 149 185
178 70 94 100 132 139 155 137 124 147 160 56 56 89 105 136 153 86 126 163
171 161 152 131 146 148 166 142 177 141 96 93 110 155 221 167 126 49 38 34
73 82 111 115 103 228 118 197 179

ALS-A05B 69

81 52 93 126 94 80 128 140 132 212 202 147 143 103 123 95 114 117 152 164
166 80 81 109 119 141 155 141 106 125 159 53 64 87 99 141 181 77 115 179
193 154 146 139 120 137 151 134 172 154 116 95 115 170 230 167 113 40 42 35
61 96 92 135 108 211 122 196 190

ALS-A06A 54

202 224 244 188 475 292 495 552 720 601 545 415 488 532 397 556 502 420 750 528
296 199 240 208 436 314 466 533 424 486 552 495 458 741 537 561 353 597 381 461
538 447 504 402 463 553 469 499 404 474 598 381 210 266

ALS-A06B 54

220 223 238 190 445 331 465 561 713 613 521 411 501 539 369 561 503 444 745 546
192 218 232 196 430 325 485 531 406 496 544 511 428 717 526 549 338 591 394 461
516 457 503 380 488 553 466 499 393 466 626 386 397 258

ALS-A07A 55

315 284 174 271 330 388 352 367 332 320 335 446 460 506 399 442 496 472 295 536
316 344 455 463 488 409 442 527 478 302 519 483 569 589 433 308 376 468 519 468
299 213 233 193 186 239 171 231 273 329 238 257 161 242 361

ALS-A07B 55

293 272 169 240 348 356 370 387 342 307 359 455 470 491 401 417 528 474 305 491
320 336 458 473 478 430 427 488 452 306 523 501 533 586 439 297 452 460 554 398
289 206 210 214 171 237 163 261 274 329 290 269 154 236 342

ALS-A08A 56

210 227 265 611 339 462 546 725 614 512 413 485 550 375 544 505 433 708 530 539
317 571 389 445 571 657 518 485 484 403 462 534 557 270 249 115 58 66 62 62
99 110 115 97 102 119 167 124 97 87 77 77 79 118 104 114

ALS-A08B 56

215 214 247 633 319 475 562 706 606 520 410 492 536 374 560 509 414 742 517 573
313 591 370 441 571 656 525 475 499 379 469 520 555 273 191 125 67 65 65 46
99 136 106 104 115 130 156 121 103 77 77 69 88 133 92 116

ALS-A09A 55

602 608 479 741 575 890 568 530 580 582 529 508 523 430 680 859 783 759 634 596
427 523 633 458 461 288 145 144 190 111 139 158 140 186 274 287 220 153 261 212
219 332 326 296 197 186 205 213 205 257 121 140 154 196 194

ALS-A09B 55

594 563 503 713 633 848 541 518 588 589 554 481 517 453 675 837 762 793 607 570
461 512 639 517 397 313 134 139 191 119 141 157 139 189 275 285 223 145 255 199
209 341 325 292 204 180 210 214 213 231 112 153 147 195 182

ALS-A10A 54

315 453 425 356 444 371 394 328 273 321 356 393 459 381 283 262 310 248 244 273
235 263 317 241 256 289 346 376 523 463 388 93 91 80 74 103 105 110 96 153
199 216 249 294 232 428 614 504 329 187 152 164 208 126

ALS-A10B 54

333 450 426 354 440 355 390 346 273 317 360 401 452 392 275 277 292 253 254 266
235 272 313 253 237 311 372 362 480 473 421 99 97 70 73 111 104 107 90 149
211 213 246 284 229 440 620 511 341 182 146 164 200 130

ALS-A11A 57

129 192 144 180 133 186 125 128 113 123 134 143 146 152 113 120 122 157 125 192
175 159 198 159 161 156 150 184 215 180 200 204 264 267 187 203 145 150 151 181
150 143 186 181 139 162 168 200 175 201 170 182 134 233 213 140 110

ALS-A11B 57

117 190 158 173 127 186 124 135 111 127 149 149 130 163 108 131 109 152 134 171
198 158 195 167 154 168 154 180 213 180 174 219 265 284 121 238 169 140 175 136
163 145 177 182 146 161 164 203 172 195 157 189 137 219 233 132 110

ALS-A12A 56

174 201 166 146 83 119 125 127 124 118 104 115 159 81 97 94 99 140 128 123
85 164 92 82 121 124 109 134 176 166 111 162 127 168 128 139 166 198 201 164
122 131 145 120 115 99 90 91 138 82 101 109 168 120 136 175

ALS-A12B 56

184 185 154 151 89 126 110 135 130 130 99 116 141 79 104 86 128 119 132 118
85 163 105 82 115 124 112 151 161 165 122 142 146 158 145 140 150 195 198 182
89 127 145 119 113 101 82 99 138 89 86 111 167 114 145 169

ALS-A13A 58

350 318 327 352 460 499 452 453 392 352 323 386 389 592 453 367 309 253 258 252
249 327 203 319 339 285 282 182 185 118 69 58 70 67 81 99 100 119 183 148
175 213 239 184 196 164 55 44 44 43 55 49 87 131 126 99 135 140

ALS-A13B 58

314 344 292 373 456 499 463 446 382 358 322 385 386 592 452 373 309 257 250 259
225 331 206 313 337 285 286 181 188 108 62 56 83 57 77 106 101 119 183 154
170 208 238 185 201 156 52 42 41 50 53 56 84 135 109 109 123 141

ALS-A14A 68

102 110 149 155 122 157 135 176 219 204 199 253 213 116 85 103 155 168 163 190
157 174 164 213 120 116 115 125 148 134 135 159 90 101 131 122 116 175 116 99
115 112 136 119 141 196 116 73 48 55 96 119 116 134 117 147 113 94 111 117
109 107 103 148 135 141 124 143

ALS-A14B 68

143 125 156 159 121 149 127 188 200 224 195 265 200 120 87 99 155 165 177 193
156 174 181 195 131 107 114 127 144 133 138 167 81 114 136 105 127 175 108 92
119 114 135 149 129 193 105 75 55 50 89 105 133 130 128 133 125 103 104 118
120 109 107 141 126 143 132 132

ALS-A15A 54

267 261 231 293 216 410 326 267 183 217 188 162 158 242 217 307 315 310 280 236
246 114 75 68 108 118 91 108 122 179 216 173 222 267 275 227 169 145 71 63
50 51 68 86 130 139 109 132 123 135 167 152 130 171

ALS-A15B 54

287 257 224 273 223 412 329 274 176 216 217 166 162 250 202 307 327 270 270 261
238 121 70 67 109 116 97 101 125 171 208 168 234 257 273 233 190 121 75 68
60 40 69 86 144 142 104 121 132 160 154 167 126 163

ALS-A16A 54

258 282 238 413 476 359 346 260 283 249 404 465 366 340 426 479 359 352 249 220
302 384 295 256 275 337 393 337 175 292 388 251 281 293 496 384 457 203 143 220
223 217 229 151 108 182 206 238 249 272 233 323 329 315

ALS-A16B 54

265 281 247 411 451 368 348 263 277 253 404 461 368 355 452 461 341 342 261 216
306 369 301 258 275 312 413 344 198 288 390 234 294 288 484 397 459 215 134 191
256 208 237 144 110 182 191 234 271 265 231 317 338 294

ALS-A17A 60

303 436 373 296 283 235 284 322 559 314 284 259 240 202 224 212 282 244 240 264
220 260 189 250 108 59 54 91 96 88 128 156 226 322 261 293 264 332 249 165
158 133 52 36 32 30 25 31 43 59 69 49 59 61 66 85 68 105 70 70

ALS-A17B 60

381 398 374 299 300 208 297 324 535 328 277 254 241 213 217 195 303 233 238 258
228 260 201 211 112 56 55 90 98 92 124 151 224 321 268 287 270 326 260 166
173 143 49 35 34 29 29 32 39 61 70 49 65 52 76 78 66 103 75 80

ALS-A18A 55

225 203 194 258 201 292 254 175 198 232 126 103 119 125 150 126 153 137 136 147
104 72 116 97 78 105 100 91 108 51 78 167 119 140 206 150 99 122 155 143
175 148 190 249 123 73 78 141 167 155 125 115 141 141 136

ALS-A18B 55

214 205 202 253 211 294 263 181 202 236 125 97 124 125 150 120 160 136 115 128
101 74 131 86 89 115 102 95 109 56 86 159 127 132 186 154 92 125 155 138
178 157 192 242 132 73 86 132 163 160 116 119 132 149 142

ALS-A19A 59

230 211 154 289 203 222 124 146 190 193 151 169 140 102 142 243 248 180 227 211
193 161 111 123 127 176 111 131 122 140 152 82 67 71 121 107 164 140 205 142
171 181 211 222 193 192 163 88 148 201 147 154 209 173 161 158 183 107 124

ALS-A19B 59

222 222 170 293 222 177 154 123 195 200 142 162 144 96 145 246 253 180 221 201
200 161 117 120 120 191 94 137 130 142 153 81 74 83 101 120 166 133 189 116
171 175 229 240 176 209 111 100 149 198 133 171 195 179 138 167 179 117 113

ALS-A20A 70

273 216 179 145 130 191 194 146 164 144 88 132 235 264 182 232 203 200 152 118
115 131 171 111 126 114 152 157 77 81 82 99 126 152 145 197 127 173 183 224
229 159 223 118 85 158 200 155 167 215 134 150 172 182 113 103 110 130 153 147
132 188 102 136 162 160 138 172 138 98

ALS-A20B 70

265 222 174 152 130 193 200 156 143 145 105 118 239 262 180 222 211 184 161 123
123 109 193 98 118 132 136 156 74 75 83 96 125 149 147 197 144 168 164 226
243 163 219 120 94 149 208 146 149 217 162 158 172 206 100 114 106 107 148 129
163 170 117 118 177 139 164 180 127 103

ALS-A21A 67

287 280 241 253 256 235 186 241 206 204 153 193 200 193 235 239 258 161 125 143
122 151 176 200 186 227 250 275 258 353 335 271 163 125 128 262 173 186 228 216
202 206 179 130 127 178 152 234 145 185 196 78 94 122 134 151 163 98 69 111
122 123 122 138 232 180 100

ALS-A21B 67

349 267 257 253 252 218 203 252 219 164 177 197 203 179 226 219 282 150 139 147
129 136 170 183 208 253 214 251 262 323 330 268 187 119 139 245 189 169 201 208
200 209 170 123 149 138 149 254 140 169 207 90 92 124 126 142 167 98 61 127
125 122 118 148 261 171 102

ALS-A22A 55

311 380 277 285 410 476 578 706 667 495 330 335 419 551 702 532 410 254 168 164
159 216 253 215 233 246 226 231 192 182 121 82 70 76 121 102 127 235 169 210
214 178 176 160 218 170 243 214 243 134 215 146 260 154 197

ALS-A22B 55

320 376 258 279 557 449 559 733 651 501 328 328 438 542 701 537 407 239 179 163
162 192 262 224 238 262 226 247 185 196 120 81 66 111 91 107 136 236 184 200
221 176 168 157 224 172 242 213 235 148 216 159 260 152 190

ALS-A23A 70

206 212 248 265 402 348 370 320 416 295 194 280 255 345 190 216 172 176 193 201
137 242 267 303 237 140 38 34 36 65 72 89 137 137 171 157 94 92 125 103
75 88 62 105 148 108 99 100 95 102 81 141 162 167 209 186 164 184 230 266
221 112 123 118 94 74 61 76 62 74

ALS-A23B 70

167 196 247 265 400 353 371 315 415 336 167 266 258 335 206 198 169 172 211 188
138 234 276 296 240 119 44 31 36 67 67 90 145 136 169 153 97 100 124 96
86 77 86 100 136 113 86 96 105 95 101 147 156 170 204 183 155 180 231 283
207 108 118 115 90 73 63 67 66 80

ALS-A24A 56

234 198 172 199 269 248 240 311 351 281 371 434 385 453 434 465 434 447 385 377
374 325 306 104 71 81 95 116 122 155 158 111 190 152 178 140 113 139 118 121
97 33 35 39 71 52 52 64 177 215 214 231 220 243 242 293

ALS-A24B 56

274 191 168 203 272 250 204 308 346 284 383 426 372 461 440 467 435 435 386 379
381 322 299 118 69 79 93 112 124 170 151 91 200 157 182 127 109 139 129 121
99 33 40 32 68 56 55 64 164 230 221 230 221 231 275 243

ALS-A25A 54

147 109 124 120 161 313 233 169 183 269 151 158 80 70 62 98 172 410 224 152
203 221 213 185 209 318 441 353 296 261 390 254 366 315 254 209 338 229 240 321
257 167 221 138 219 205 262 122 127 171 136 139 69 127

ALS-A25B 54

133 110 131 110 168 145 278 167 190 246 197 155 78 59 69 81 173 396 232 153
226 208 215 173 215 288 471 329 304 271 391 273 365 317 240 214 338 227 288 318
253 151 240 144 195 209 279 104 136 168 131 130 82 132

ALS-A26A 57

159 321 113 58 163 249 377 244 334 350 264 203 299 227 246 202 86 44 49 89
153 230 234 273 270 235 309 244 191 75 64 85 157 304 182 220 177 85 204 254
289 302 136 219 200 224 78 78 81 119 124 124 132 214 212 253 301

ALS-A26B 57

143 337 103 51 173 214 375 246 294 293 286 216 297 223 268 199 75 48 48 71
163 226 252 264 255 247 296 225 207 86 55 60 148 288 193 236 174 104 204 265
299 312 128 250 178 239 83 64 68 115 146 145 158 149 269 220 344

ALS-A27A 65

146 140 193 376 247 210 252 292 251 299 256 212 121 139 120 116 142 198 158 78
54 32 46 48 81 108 109 97 67 102 106 136 60 56 72 88 116 104 176 128
47 122 82 114 101 170 172 179 277 168 57 47 58 83 63 83 86 134 135 120
112 92 146 200 124

ALS-A27B 65

201 167 198 368 252 209 246 324 254 278 243 207 138 138 124 128 148 182 157 77
46 42 38 51 81 88 109 88 70 95 112 97 61 68 72 88 104 98 191 128
61 104 86 114 96 170 172 197 275 155 51 50 50 95 57 70 85 143 136 124
126 99 135 204 150

ALS-A28A 58

199 137 195 190 309 239 220 137 179 163 238 234 239 205 154 187 165 129 114 77
54 76 97 178 172 236 152 146 169 231 253 243 196 141 153 160 146 153 210 231
216 187 113 98 123 53 58 50 56 74 115 107 137 125 142 172 148 180

ALS-A28B 58

234 155 189 181 312 236 208 150 168 182 224 238 259 193 154 108 151 125 118 75
51 81 95 176 177 238 136 159 148 248 239 245 202 148 150 160 128 174 243 219
242 176 116 104 138 45 43 62 74 71 105 107 117 122 132 167 152 192

ALS-A29A 87

40 58 74 118 46 62 74 85 51 52 62 60 59 93 58 72 66 60 82 72
90 91 46 43 44 43 35 47 41 51 55 44 98 61 83 80 50 36 34 48
49 43 62 72 71 77 79 77 96 76 90 135 125 76 140 102 169 213 112 148
40 44 47 47 78 92 104 97 75 56 50 58 65 105 140 118 126 140 86 108
87 79 68 80 108 125 123

ALS-A29B 87

41 50 80 111 50 61 73 85 51 54 63 62 58 78 71 66 73 60 77 70
94 97 45 38 46 43 37 51 34 58 37 52 100 65 86 72 42 36 34 50
46 49 66 61 72 77 76 83 91 87 83 137 123 85 130 110 170 208 114 149
41 45 47 40 85 93 104 98 75 57 45 55 70 104 134 105 131 141 90 116
90 74 75 78 117 115 115

ALS-A30A 54

260 213 208 226 224 156 104 478 288 228 190 234 226 176 90 120 147 111 229 285
346 348 339 266 157 118 46 40 18 38 44 48 57 57 52 85 85 93 125 103
74 71 94 111 111 117 155 135 110 89 70 52 58 64

ALS-A30B 54

242 207 208 230 240 216 104 420 272 253 210 230 221 181 92 123 125 128 213 286
326 364 334 280 158 119 47 38 25 30 47 30 62 50 59 88 101 99 135 92
76 67 97 113 111 120 154 142 112 80 56 66 68 91

ALS-A31A 57

435 463 423 413 364 361 387 337 280 109 73 84 88 113 111 159 147 91 198 148
199 131 116 148 112 125 65 47 38 44 59 57 57 62 174 192 216 239 228 252
42 96 51 28 38 56 58 72 86 79 47 69 127 127 76 53 66

ALS-A31B 57

406 458 424 420 364 349 384 330 267 100 76 70 98 118 109 160 135 102 186 156
191 129 114 154 120 113 44 41 41 53 73 61 51 64 173 226 228 249 203 255
43 96 46 28 36 68 57 71 80 74 52 69 132 126 68 121 102

ALS-A32A 56

100 88 93 126 126 214 212 147 161 156 140 180 288 276 248 272 258 374 456 152
230 73 93 108 84 106 118 86 96 64 46 68 57 113 90 126 79 67 63 70
77 72 56 53 49 60 95 93 108 121 139 234 128 154 70 89

ALS-A32B 56

112 65 106 127 119 224 204 144 168 152 147 177 286 286 244 292 282 366 512 160
215 81 82 80 84 117 107 70 99 63 48 63 56 109 100 122 88 60 67 60
75 72 56 50 52 62 96 86 109 119 126 232 128 163 72 89

ALS-A33A 54

211 115 166 152 109 97 119 118 123 111 126 81 134 90 94 84 116 112 98 92
91 116 89 86 122 109 133 84 96 81 112 93 76 128 106 85 105 94 125 79
64 122 101 86 135 182 80 101 137 105 95 126 127 181

ALS-A33B 54

198 122 145 158 121 89 126 120 106 129 104 91 118 103 109 88 108 121 99 83
99 114 90 80 120 98 141 91 86 97 86 94 87 107 106 108 90 98 104 95
64 139 99 85 137 175 90 106 133 87 104 122 98 166

ALS-A34A 54

156 161 143 155 243 108 93 152 94 95 89 102 128 102 100 107 129 155 127 142
110 86 87 133 121 97 112 77 95 106 91 149 230 272 180 136 176 168 138 94
90 122 200 152 190 125 142 87 154 124 120 90 114 154

ALS-A34B 54

166 168 144 149 249 104 89 150 97 84 100 99 135 104 94 106 138 147 131 133
121 83 91 128 119 114 91 84 89 102 83 157 230 257 189 141 182 159 136 75
114 96 220 139 197 118 154 81 135 120 132 96 116 153

ALS-A35A 57

95 97 87 105 62 87 82 66 90 110 69 58 101 130 98 86 76 140 118 111
117 119 136 176 148 117 116 98 130 140 100 118 115 94 87 114 97 82 120 122
117 140 122 118 141 115 113 122 131 172 110 109 144 180 193 82 95

ALS-A35B 57

73 102 85 97 67 87 77 67 92 100 66 64 104 129 116 76 69 143 134 93
133 124 117 180 160 103 117 94 136 136 91 105 108 99 101 98 98 83 123 113
136 128 151 106 126 160 122 124 146 154 130 102 120 211 141 96 82

ALS-A36A 57

69 74 62 76 90 86 76 104 78 94 110 58 52 84 88 84 66 73 93 72
66 62 57 118 91 107 97 76 72 89 103 69 75 82 57 69 69 77 81 61
84 64 53 62 60 81 82 80 94 74 72 76 79 80 67 96 83

ALS-A36B 57

73 88 59 63 107 81 75 103 83 93 97 58 51 80 86 79 77 68 96 68
69 62 57 108 101 103 98 74 70 88 103 71 68 84 62 64 66 78 84 54
82 69 53 62 59 77 93 72 79 77 89 86 54 89 69 89 84

ALS-A37A 54

115 103 155 82 61 42 55 68 136 46 62 116 142 173 97 48 42 105 223 225
247 190 148 67 56 67 78 98 160 98 66 134 192 222 219 192 157 262 184 118
256 215 105 176 132 118 136 120 140 98 148 94 94 124

ALS-A37B 54

109 107 156 60 51 47 43 83 116 72 92 116 147 175 90 56 48 97 205 222
240 193 154 87 56 72 64 114 164 91 72 135 197 209 201 199 156 249 189 104
242 222 105 165 148 108 137 119 136 102 142 114 76 142

ALS-A38A 55

105 133 113 177 150 154 91 85 81 55 78 91 82 125 126 147 97 126 112 134
187 183 173 129 88 100 74 116 92 195 98 89 126 96 108 85 214 167 188 113
131 163 99 104 119 34 151 139 177 140 140 132 138 126 122

ALS-A38B 55

117 105 142 180 148 131 112 75 79 61 57 95 82 122 135 141 77 159 89 138
204 177 174 128 95 90 79 121 102 177 96 92 117 101 112 81 213 174 184 130
116 133 125 90 104 60 144 140 168 150 138 123 135 128 124

ALS-A39A 59

190 262 131 206 202 200 178 195 90 118 160 156 106 86 65 121 99 79 112 104
64 76 72 69 156 114 165 116 113 107 74 72 50 66 49 88 87 133 105 117
116 127 94 132 135 117 92 124 96 150 126 120 86 136 94 112 78 106 119

ALS-A39B 59

197 254 130 200 194 218 180 193 79 130 173 171 110 82 59 113 100 91 109 111
95 74 68 71 147 122 142 136 101 124 77 57 52 54 75 71 74 133 121 106
134 111 96 131 140 109 84 156 79 151 105 134 78 133 90 110 94 118 104

ALS-A40A 54

107 115 163 103 78 75 117 98 103 117 84 134 120 126 120 196 134 128 172 168
158 114 124 146 82 152 126 149 186 141 68 112 116 97 194 149 268 92 128 82
110 69 80 81 94 98 104 119 122 110 99 106 115 139

ALS-A40B 54

112 125 153 101 88 68 126 103 100 117 94 135 123 126 119 197 132 124 179 156
168 117 115 155 91 118 152 132 179 139 111 116 117 114 174 149 255 134 102 80
80 78 77 77 109 97 106 125 106 115 88 120 112 140

ALS-A41A 54

189 291 331 270 344 306 241 167 188 138 141 323 218 182 176 283 391 415 321 332
282 176 114 142 123 149 130 162 105 131 139 126 127 93 88 93 83 67 60 56
46 49 41 43 44 42 38 32 45 48 64 48 33 39

ALS-A41B 54

135 298 358 271 349 330 246 159 186 136 153 352 222 177 170 281 358 350 320 328
278 170 116 144 132 168 122 165 95 140 125 129 122 104 80 96 82 86 52 60
46 48 40 45 46 41 38 34 44 48 52 56 54 54

ALS-A42A 58

156 272 295 241 284 192 208 256 409 293 306 193 220 253 132 100 88 88 75 144
156 127 135 187 266 280 223 123 114 110 90 70 203 261 316 312 159 129 110 98
133 95 100 134 98 124 128 110 51 86 62 64 121 65 41 47 47 84

ALS-A42B 58

228 284 294 233 273 200 216 256 409 285 302 193 229 248 134 104 92 84 80 152
148 126 138 197 249 284 244 121 119 124 108 79 201 262 305 317 160 119 110 95
128 86 100 142 84 124 146 94 61 85 52 62 127 55 49 38 46 88

ALS-A43A 69

161 176 170 110 158 169 124 215 191 212 281 207 337 268 311 166 207 113 165 290
154 132 110 207 255 154 250 304 376 214 132 138 198 226 229 337 168 167 310 339
110 253 160 150 125 157 190 162 157 151 159 153 227 165 484 195 170 143 114 115
208 538 196 181 225 226 198 124 128

ALS-A43B 69

161 182 164 114 165 165 130 209 187 192 284 238 300 275 290 177 188 126 161 277
130 116 126 236 241 165 208 309 360 224 163 136 205 215 220 333 173 164 316 352
98 253 153 150 133 148 183 182 146 174 160 149 237 154 483 190 176 123 125 123
209 507 205 181 232 220 187 129 142

ALS-A44A 60

343 422 446 386 372 360 241 175 151 279 290 231 232 296 437 397 351 312 291 214
168 283 304 307 315 226 206 143 170 169 108 85 49 64 128 156 162 304 92 146
94 110 91 99 85 81 94 122 57 103 102 105 99 68 132 137 167 131 110 117

ALS-A44B 60

314 414 380 421 353 302 241 157 145 289 303 252 231 325 444 388 352 317 309 202
167 269 282 304 324 220 196 155 154 173 93 83 64 74 136 133 179 314 86 147
79 121 91 94 89 83 91 107 56 107 110 107 97 65 133 123 180 126 102 113

ALS-A45A 54

219 275 218 238 355 394 264 310 382 333 331 297 372 381 242 385 493 531 611 425
144 86 51 55 56 71 92 134 118 152 206 204 188 138 110 126 95 78 73 247
150 258 131 119 109 178 178 155 166 181 265 271 232 328

ALS-A45B 54

211 268 228 231 358 387 261 319 390 316 333 298 367 388 242 360 489 525 611 437
168 66 47 56 55 88 82 136 109 169 186 205 188 139 116 115 92 69 88 258
151 258 138 117 105 174 178 160 162 196 261 279 234 328

ALS-A46A 54

357 410 556 439 416 430 368 203 195 260 254 378 454 336 434 406 322 250 276 314
397 519 410 535 542 640 460 176 339 336 449 99 104 273 204 306 300 210 331 360
363 476 419 308 307 336 276 272 370 300 329 287 462 647

ALS-A46B 54

403 536 549 433 384 399 379 205 170 255 233 360 457 359 422 404 346 239 286 309
395 495 431 557 570 673 614 174 442 402 511 93 111 262 217 323 292 205 324 368
370 487 406 328 318 332 280 273 379 310 389 263 500 528

ALS-A47A 82

302 464 511 245 216 213 243 228 266 174 244 143 167 328 176 308 282 179 202 151
124 152 168 155 156 122 85 154 158 98 129 103 132 125 100 156 167 82 102 94
229 183 173 119 174 82 129 97 83 113 130 54 47 95 76 89 87 91 48 53
79 53 85 72 79 77 113 60 58 44 50 37 92 93 110 118 60 114 82 46
122 92

ALS-A47B 82

302 483 522 240 218 212 244 220 252 171 253 146 162 334 166 298 278 198 196 153
115 154 161 172 159 118 101 148 156 99 126 109 136 119 98 146 182 74 95 116
243 177 159 134 161 78 127 101 89 94 131 51 46 92 74 94 78 104 44 44
82 62 86 68 90 74 101 69 50 46 57 38 84 103 111 113 56 112 74 94
102 101

ALS-A48A 54

178 337 108 301 153 163 135 82 114 136 112 128 65 86 143 112 92 126 133 167
216 204 114 104 131 196 282 173 170 115 115 108 106 106 80 73 85 126 208 170
149 138 140 110 123 81 83 101 110 138 103 87 54 100

ALS-A48B 54

196 305 112 278 149 171 137 77 120 128 119 137 62 78 134 116 97 122 142 165
214 197 133 94 118 199 289 165 175 117 109 105 109 110 80 74 74 124 224 168
165 129 154 108 118 80 89 89 112 150 92 100 36 114

ALS-A49A 75

236 240 317 433 293 410 374 335 320 268 206 352 386 329 389 322 230 350 339 239
198 259 278 176 212 191 234 100 138 124 272 307 271 187 198 103 140 104 124 210
175 204 165 238 140 195 112 127 159 171 236 203 181 187 175 192 202 168 135 134
83 122 186 280 186 169 134 241 160 143 141 272 272 243 192

ALS-A49B 75

222 268 204 468 302 385 368 366 348 269 206 341 392 335 386 331 246 352 342 243
209 242 298 168 220 174 230 91 147 122 294 274 284 192 192 96 148 108 109 222
189 196 164 239 141 188 102 128 148 164 230 196 170 190 187 187 203 163 148 121
112 126 180 283 194 170 134 238 161 145 125 272 249 226 156

ALS-A50A 103

333 421 275 210 274 284 273 139 64 171 151 204 297 155 112 192 200 179 121 164
178 301 173 130 95 103 170 231 140 239 230 183 229 175 250 154 164 191 119 224
84 129 110 92 210 101 267 134 179 101 52 95 63 52 60 121 121 92 147 80
93 120 99 159 116 89 74 47 51 52 50 96 91 91 93 103 58 53 56 61
50 158 170 142 126 72 130 75 87 68 72 116 108 122 110 120 182 198 136 91
73 44 84

ALS-A50B 103

349 386 202 205 266 283 366 133 68 164 147 207 307 166 115 185 199 200 139 174
165 323 165 123 105 103 172 221 153 237 211 188 229 201 257 161 154 200 132 240
93 125 127 87 205 117 249 141 180 112 52 98 42 58 66 105 133 92 151 123
88 132 94 168 109 87 74 48 52 49 51 90 82 102 78 112 58 52 50 56
60 158 164 142 134 69 135 94 81 70 69 126 116 124 101 127 187 172 147 88
63 49 56

ALS-A51A 55

349 317 324 260 251 192 113 164 138 227 394 351 317 269 273 306 226 106 79 42
48 68 110 119 113 121 103 123 112 127 137 60 104 123 97 100 116 107 135 166
119 91 80 102 134 101 72 83 114 85 112 80 56 65 91

ALS-A51B 55

349 317 316 266 256 195 131 205 138 223 393 344 322 310 303 289 205 103 81 42
46 67 116 122 103 119 117 107 125 142 117 92 89 108 102 111 117 110 149 158
115 86 74 102 122 116 58 98 104 97 108 90 56 59 70

ALS-A52A 76

82 79 44 79 62 95 54 65 105 114 190 101 76 89 73 105 234 171 195 206
177 112 76 75 105 101 96 87 165 120 154 185 230 256 163 117 96 101 103 107
124 140 310 263 356 326 262 260 223 175 214 242 257 230 182 257 201 217 201 172
152 173 143 123 167 154 219 202 137 283 149 145 100 177 131 136

ALS-A52B 71

82 90 27 70 68 68 58 67 124 122 108 102 79 90 98 109 229 182 204 162
162 94 79 72 120 119 90 84 165 94 177 194 211 263 202 114 99 107 121 107
113 135 313 267 371 296 259 253 218 176 207 248 272 218 189 263 212 173 177 193
136 149 162 124 164 165 224 200 139 260 137 135 104 176 127 142

ALS-A53A 54

93 87 98 98 140 240 222 220 284 129 77 83 61 83 92 249 293 350 467 396
404 393 362 267 161 186 260 411 391 427 370 401 477 543 464 405 362 280 385 360
332 195 336 312 215 185 278 310 396 223 316 307 211 210

ALS-A53B 54

84 83 109 85 140 228 233 242 283 128 72 87 59 70 101 244 272 327 461 397
396 418 345 294 166 191 241 414 394 417 377 397 476 548 437 432 370 278 393 355
319 198 338 306 211 196 271 296 390 273 315 313 207 257

ALS-A54A 55

344 329 176 306 306 268 229 225 141 170 115 163 124 127 437 449 529 373 312 328
357 346 269 354 259 199 266 241 187 307 173 144 171 135 173 190 216 266 325 274
354 297 171 103 190 157 153 151 132 154 122 163 130 163 141

ALS-A54B 55

355 333 183 295 318 264 218 232 141 185 107 160 130 130 433 456 480 413 330 256
341 341 282 346 250 221 247 223 183 293 176 143 167 143 173 189 221 258 331 272
359 285 152 122 190 159 134 163 136 168 122 149 135 148 162

ALS-A55A 54

94 103 86 170 116 149 127 163 127 118 201 144 141 177 140 163 199 152 113 110
91 155 131 155 110 101 126 114 130 226 208 173 154 151 124 157 102 121 106 89
210 156 149 58 99 107 115 107 94 183 129 154 84 97

ALS-A55B 54

124 96 100 167 118 137 131 162 122 140 181 168 124 154 160 163 190 159 120 103
90 147 137 142 126 93 145 112 122 226 208 173 147 149 129 159 97 125 97 105
201 166 151 64 84 109 112 111 98 168 120 162 94 104

ALS-A56A 56

227 190 120 199 239 210 177 201 167 151 146 145 166 173 176 209 244 233 240 197
140 193 249 319 204 183 223 176 132 158 94 103 90 79 160 171 152 166 192 198
161 146 118 118 162 218 228 168 176 150 180 153 115 80 128 134

ALS-A56B 56

244 174 131 205 279 200 184 200 178 138 157 156 152 186 164 187 241 237 239 209
133 200 247 317 217 187 216 160 133 154 103 102 80 90 156 161 162 161 183 232
169 144 123 112 163 221 225 167 174 156 173 159 107 78 118 133

ALS-A57A 98

132 90 74 60 54 78 80 107 145 138 147 114 45 25 33 48 80 60 74 141
143 130 113 136 124 124 73 73 103 91 78 71 67 169 123 170 204 213 185 168
144 218 184 173 171 190 187 226 197 164 215 144 211 203 83 85 42 53 32 41
53 86 86 92 92 59 49 37 37 42 99 152 190 249 254 274 179 118 131 79
154 129 160 129 193 200 161 192 152 94 65 87 123 170 178 196 178 216

ALS-A57B 98

125 90 67 57 59 77 69 119 132 149 151 111 42 23 31 51 78 68 67 151
134 139 120 133 111 112 72 76 103 100 67 76 86 167 122 166 204 198 195 163
145 215 187 162 178 195 180 227 207 167 218 154 210 191 86 80 41 48 35 42
52 88 83 95 86 67 47 39 30 51 93 149 188 259 263 281 162 114 133 85
132 146 150 132 197 199 150 194 149 87 77 87 122 170 180 187 193 167

ALS-A58A 66

207 325 252 393 317 263 145 159 210 196 252 223 191 334 256 225 297 170 178 103
117 130 93 82 99 105 149 223 90 83 58 36 35 38 32 45 75 80 93 120
75 81 55 46 53 49 68 67 93 112 150 189 229 167 106 73 53 54 118 254
240 131 111 185 114 143

ALS-A58B 66

199 328 269 394 317 250 156 151 209 191 266 230 188 343 262 229 292 175 174 102
117 129 96 87 98 108 150 232 73 79 56 31 38 34 39 41 82 77 92 120
74 81 63 44 56 48 64 69 90 114 144 204 228 159 113 61 54 53 118 249
220 121 114 209 121 116

ALS-A59A 86

109 234 114 185 234 159 169 259 176 190 106 99 142 221 143 116 101 122 138 237
133 254 184 137 138 150 102 93 120 167 133 109 45 69 83 54 135 108 212 175
233 162 87 121 78 96 66 159 147 154 188 167 99 117 133 192 140 90 66 68
51 43 58 74 61 80 61 87 34 40 35 35 32 60 67 48 63 49 77 74
61 63 57 88 67 118

ALS-A59B 86

148 229 110 206 233 148 161 250 181 191 97 100 140 230 136 119 98 106 147 234
136 251 202 123 153 143 124 107 110 185 103 107 64 65 97 50 143 101 206 176
242 172 95 115 70 93 71 156 144 157 192 156 115 118 128 201 128 72 72 59
51 45 52 80 69 79 62 76 42 37 35 32 36 71 67 62 50 57 73 76
55 72 56 86 71 101

ALS-A60A 57

452 298 223 234 190 189 268 226 212 196 372 433 448 312 203 234 182 170 205 278
218 213 191 217 218 132 117 113 103 221 193 175 117 166 219 172 282 213 126 101
74 139 154 187 249 176 316 257 222 221 310 250 330 264 174 263 233

ALS-A60B 57

437 316 209 235 187 192 277 223 202 198 404 428 430 298 213 241 200 159 196 282
208 211 212 205 185 163 106 111 105 214 192 170 116 167 207 179 292 205 133 98
73 137 158 177 255 179 311 259 220 215 301 251 333 257 167 268 212

ALS-A61A 55

121 172 163 182 141 199 192 200 248 149 173 127 213 148 120 176 122 82 108 165
64 210 134 127 112 136 169 124 163 152 158 140 84 103 181 162 154 160 138 107
129 187 94 121 151 113 166 125 198 150 129 140 135 131 157

ALS-A61B 55

114 176 165 178 142 198 195 184 261 147 173 113 224 155 120 180 114 80 118 147
71 220 133 124 115 133 169 133 156 147 164 149 74 97 185 162 157 155 141 117
123 171 102 132 129 120 162 146 182 169 115 142 135 148 150

ALS-A63A 54

107 78 86 83 105 82 58 103 29 147 84 73 81 137 91 99 64 120 78 54
91 73 78 105 106 117 94 64 129 99 94 112 113 113 119 96 133 73 105 107
83 129 142 133 113 162 91 95 54 113 110 84 92 97

ALS-A63B 54

100 85 77 93 100 84 59 118 33 130 78 75 76 149 84 94 79 106 78 55
92 80 76 109 100 118 92 71 113 113 87 110 111 109 130 94 134 75 105 113
81 122 148 124 124 158 95 92 55 113 103 98 85 90

ALS-A64A 55

250 271 170 154 143 141 154 152 134 88 35 93 125 152 113 162 232 139 143 191
218 177 247 181 246 288 170 133 90 77 131 125 202 177 213 136 131 127 106 124
138 177 168 124 159 163 135 176 153 197 168 134 159 122 113

ALS-A64B 55

210 272 165 157 142 151 147 162 127 84 40 95 123 157 92 163 239 146 134 174
212 171 226 189 254 291 162 125 97 91 112 126 203 179 201 158 119 129 96 121
153 184 170 127 164 135 136 167 167 191 170 140 160 102 101

ALS-A65A 54

223 469 487 374 379 374 366 301 87 50 41 50 51 136 140 223 314 131 81 110
80 55 67 58 125 254 190 320 263 261 325 264 341 371 184 202 154 103 173 117
196 230 189 243 208 113 88 92 113 138 238 303 295 304

ALS-A65B 54

212 459 488 375 391 389 388 293 91 43 52 43 35 132 131 233 306 130 92 103
82 53 60 73 121 270 184 356 270 261 313 281 334 388 180 169 140 100 141 109
183 248 196 241 191 115 90 80 113 143 230 291 284 303

ALS-A66A 69

152 146 264 273 368 280 257 183 154 136 112 119 104 190 188 144 190 147 166 176
147 218 188 148 218 134 92 114 108 124 211 242 263 230 112 69 58 65 78 172
91 116 173 129 157 129 126 109 86 156 170 184 129 233 243 286 250 177 124 79
95 198 243 252 248 184 255 186 247

ALS-A66B 69

148 149 274 283 372 291 261 170 135 146 108 112 107 154 164 145 207 151 155 178
146 203 183 148 183 146 85 110 102 133 214 232 234 240 99 76 57 71 84 135
91 116 179 123 159 110 85 112 104 151 160 181 149 249 245 290 248 171 116 93
94 184 245 236 237 220 287 179 174

ALS-A67A 54

215 157 269 159 141 197 212 123 150 178 185 196 146 173 211 70 105 84 165 197
153 160 144 84 113 86 79 108 104 106 89 151 71 82 57 62 73 68 144 126
145 120 153 118 134 125 103 69 74 78 101 124 143 150

ALS-A67B 54

257 149 232 155 132 210 209 139 136 176 177 184 133 172 206 91 98 90 141 210
153 153 136 96 104 94 85 104 93 99 109 164 77 93 50 60 73 64 139 131
142 123 146 121 134 123 101 67 77 68 104 121 137 174

ALS-A68A 90

631 454 453 408 392 301 243 233 216 223 319 238 291 399 327 355 368 241 171 201
178 191 182 135 66 38 46 80 85 135 156 127 108 134 148 123 195 163 264 205
172 200 218 171 197 134 105 80 73 111 70 88 83 96 124 145 208 187 122 86
66 67 63 120 278 291 235 207 236 227 156 165 204 191 229 240 185 175 199 190
227 188 150 96 124 161 205 154 206 155

ALS-A68B 90

688 469 441 423 386 311 239 233 231 238 301 224 281 390 318 391 358 228 182 200
192 186 171 157 77 39 41 85 81 147 146 113 127 136 138 126 198 195 270 208
164 207 206 182 190 134 101 83 83 118 67 81 94 98 118 155 206 185 149 86
72 57 65 135 272 290 230 215 229 233 156 154 198 186 248 213 196 186 215 198
223 176 141 93 123 160 175 182 204 179

ALS-A69A 54

157 104 143 83 100 62 53 69 59 73 111 186 192 205 131 112 88 120 137 197
225 226 254 220 201 169 148 174 192 237 259 258 174 354 323 299 161 163 122 130
138 221 339 313 277 272 371 241 242 134 123 137 142 142

ALS-A69B 54

168 132 125 86 98 70 53 62 62 75 121 221 219 166 98 100 87 119 124 190
229 237 258 202 208 177 148 179 175 245 256 252 174 355 321 271 178 176 114 127
145 228 326 323 276 279 361 232 253 147 142 125 142 134

ALS-A70A 61

341 327 271 245 188 127 197 168 187 253 162 136 188 222 162 148 201 219 138 113
178 216 98 128 125 189 145 94 90 104 58 88 83 69 86 113 127 102 137 84
69 58 63 72 87 146 143 180 142 160 136 161 152 136 93 90 103 138 154 222
245

ALS-A70B 61

316 335 264 264 235 118 187 182 169 259 140 152 193 202 167 161 194 209 129 118
181 210 99 126 115 199 167 100 85 97 68 88 80 69 84 116 132 90 132 91
75 56 62 72 75 168 143 180 143 187 134 166 154 143 89 89 104 137 163 216
219

ALS-A71A 55

202 216 213 207 120 128 152 131 121 130 121 159 152 109 114 427 430 328 155 159
76 114 106 68 134 157 159 114 156 89 142 73 84 132 118 246 181 169 122 155
133 120 98 80 89 72 99 162 243 203 209 122 124 77 97

ALS-A71B 55

188 222 206 215 114 126 163 143 104 113 134 176 148 111 125 511 434 296 201 141
85 113 95 75 130 152 173 123 163 98 129 85 91 126 119 248 175 185 129 138
132 136 88 77 90 66 110 159 244 218 237 122 125 76 95

ALS-A72A 54

193 171 207 185 81 147 155 215 257 282 384 390 598 510 311 220 308 459 369 529
292 329 140 90 98 91 117 113 86 94 90 59 153 150 159 266 158 123 41 56
62 46 82 146 134 113 228 208 229 253 364 409 287 301

ALS-A72B 54

225 201 249 224 84 156 164 219 248 279 419 390 600 498 317 221 361 440 366 520
305 323 141 100 93 84 108 121 86 85 86 67 193 170 174 264 176 108 54 49
54 63 80 140 132 116 230 207 239 255 378 426 272 364

ALS-A73A 47

417 646 454 361 462 341 260 394 235 296 127 71 72 75 103 134 101 126 145 157
324 304 282 349 214 91 54 30 42 60 52 88 128 128 145 272 258 280 278 376
362 241 336 251 169 200 196

ALS-A73B 47

490 650 449 363 444 352 246 392 201 306 138 66 77 69 110 109 120 125 139 160
323 298 281 348 213 87 61 36 32 49 50 97 127 136 138 275 247 286 267 381
355 252 328 246 160 222 173

ALS-A74A 57

252 358 354 252 298 442 463 355 295 238 318 416 268 231 292 182 109 64 100 125
182 310 234 206 153 137 93 99 68 50 63 55 82 71 91 77 118 101 95 106
77 93 96 80 113 94 77 77 101 105 78 110 105 81 66 75 95

ALS-A74B 57

263 356 348 262 299 422 468 371 305 223 325 392 317 231 257 175 97 73 92 121
181 302 233 204 157 138 91 96 74 58 64 50 81 78 96 86 128 92 99 114
81 100 106 90 105 110 68 94 109 84 89 94 93 67 60 93 73

ALS-A75A 92

183 257 116 69 97 91 73 61 98 108 151 142 116 151 130 123 132 106 110 99
69 75 116 95 79 105 86 52 81 97 107 144 118 77 179 224 114 58 68 86
84 80 106 142 182 137 130 139 85 83 134 185 216 239 98 55 50 58 83 107
84 94 67 79 148 104 89 85 47 33 37 48 58 60 52 65 88 117 114 108
121 95 114 142 152 150 178 185 243 290 135 161

ALS-A75B 92

209 241 132 70 81 79 72 66 95 106 127 144 123 148 118 126 150 116 102 100
82 96 117 85 100 90 89 55 73 86 107 144 111 92 168 235 114 54 73 81
91 72 106 149 174 139 137 133 82 87 131 179 222 247 104 59 46 68 77 107
93 90 64 81 140 108 91 83 39 34 37 51 56 64 54 66 88 101 101 112
112 97 128 149 148 137 167 180 238 305 135 172

ALS-A76A 88

229 389 219 334 246 129 240 237 302 329 225 176 136 172 281 237 250 162 175 283
218 243 274 338 158 173 147 156 279 166 84 115 113 208 186 364 284 241 120 144
146 156 201 170 214 145 150 166 141 122 147 135 151 127 80 95 77 59 73 77
129 172 64 61 44 35 40 33 53 59 128 112 101 108 60 40 48 34 35 38
61 75 48 73 56 83 87 120

ALS-A76B 88

358 376 226 291 251 127 241 252 299 311 214 177 140 176 286 219 260 170 163 296
235 241 275 333 176 163 132 183 275 165 66 119 97 240 176 356 281 238 130 136
140 163 196 179 207 168 136 170 137 127 150 137 159 127 84 93 72 69 67 79
129 170 68 66 39 39 32 50 55 52 121 109 103 102 57 58 47 27 42 42
61 68 69 55 59 75 94 112

ALS-A77A 56

159 201 241 183 182 229 205 134 133 104 160 124 142 81 83 154 74 83 79 79
133 83 94 77 98 83 52 47 36 58 74 101 87 108 116 76 39 49 46 42
82 58 55 99 110 102 238 247 168 232 185 80 187 153 189 224

ALS-A77B 56

156 202 242 178 176 247 202 137 131 99 168 115 137 113 97 142 72 78 76 78
133 82 91 76 88 94 59 40 47 53 75 99 92 103 119 81 32 56 42 42
74 66 58 87 102 101 241 247 189 213 190 72 195 152 183 248

ALS-A78A 54

127 154 66 135 90 79 179 196 73 68 67 109 141 131 141 171 162 100 149 153
130 123 138 74 103 84 82 36 78 110 104 114 76 104 126 126 72 140 127 46
85 46 39 72 141 56 116 106 131 59 119 178 239 227

ALS-A78B 54

118 145 74 130 97 78 176 189 76 70 70 109 145 128 133 172 171 92 146 156
140 119 149 62 103 89 78 39 82 110 94 111 78 108 122 131 71 145 122 48
83 45 42 64 142 60 116 101 132 67 113 179 255 216

ALS-A79A 62

68 134 126 214 424 168 138 143 184 91 109 107 286 166 88 63 79 61 63 76
63 68 50 59 31 21 38 58 51 13 46 37 99 59 86 114 109 76 85 71
104 96 125 146 197 64 44 78 38 65 64 72 90 115 118 184 214 135 168 160
96 171

ALS-A79B 62

80 128 118 242 421 184 131 158 198 86 113 113 275 162 90 72 77 76 56 63
60 71 46 65 47 34 35 48 42 31 42 28 100 57 87 113 105 74 88 66
105 95 129 145 227 60 56 78 38 53 62 72 90 102 131 174 212 138 150 136
101 172

ALS-A80A 55

63 41 67 44 61 74 87 83 82 89 285 255 359 307 176 210 161 130 145 183
207 263 375 73 52 41 22 39 62 64 75 57 45 57 78 91 96 118 220 205
179 172 74 136 144 204 198 190 143 153 181 170 76 147 189

ALS-A80B 55

55 32 62 47 57 76 88 84 83 99 257 242 266 286 210 217 134 128 146 176
201 244 384 71 52 36 28 45 53 66 73 53 51 51 77 95 93 105 183 223
164 159 86 160 188 223 216 200 124 160 183 177 69 139 190

ALS-A81A 84

29 21 23 28 20 30 25 28 27 22 62 66 104 36 20 36 21 34 17 13
52 42 34 28 91 103 137 156 161 178 113 88 160 270 373 334 402 372 464 497
422 415 434 483 465 467 364 341 400 281 60 35 45 44 75 102 104 79 147 165
192 172 183 140 64 44 63 81 107 148 133 126 82 79 94 93 133 82 100 84
88 91 75 98

ALS-A81B 84

28 22 24 27 26 29 27 29 25 22 60 66 103 39 26 33 20 34 12 12
37 53 36 24 93 125 132 159 161 171 124 88 157 277 377 329 400 384 472 501
402 428 433 482 459 473 363 341 394 285 60 35 41 33 78 106 103 74 145 168
201 163 179 142 63 42 68 86 96 145 144 116 86 78 96 90 133 82 94 83
94 75 97 94

of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

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

4. ***Estimating the Felling Date.*** As mentioned above, if the bark is present on a sample, then the date of its last ring is the date of the felling of its tree. 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, sapwood can be seen in the corner of the rafter and at the outer end of the core in Figure 2, both indicated by arrows. More importantly for dendrochronology, the sapwood is relatively soft and so liable to insect attack and wear and tear. The builder, therefore, may remove some of the sapwood for precisely these reasons. Nevertheless, if at least some of the sapwood rings are left on a sample, we will know that not too many rings have been lost since felling so that the date of the last ring on the sample is only a few years before the date of the original last ring on the tree, and so to the date of felling.

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

Even more precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure 2 was taken still had complete sapwood but that none of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 2 cm, a reasonable estimate can be made of the number of sapwood rings lost, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 35 years later we would have estimated without this observation. In the example, the felling is now estimated to

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

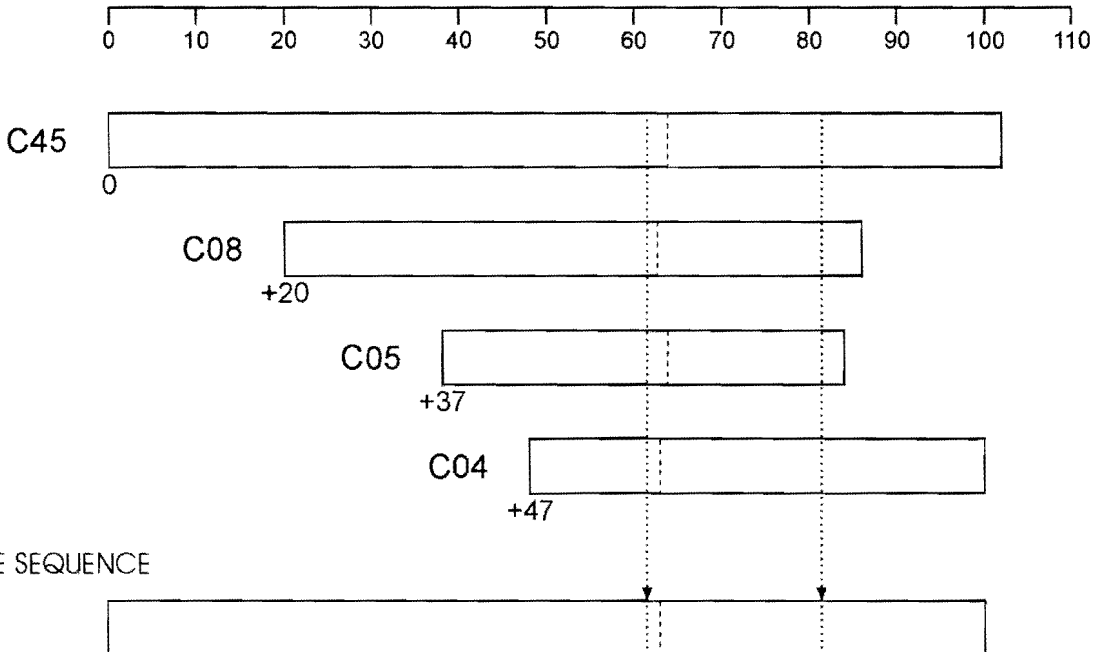


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

have taken place between AD 1512 and 1515, which is much more precise than without this extra information.

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

5. ***Estimating the Date of Construction.*** There is a considerable body of evidence collected by dendrochronologists over the years that oak timbers used in buildings were not seasoned in medieval or early modern times (English Heritage 1998 and Miles 1997, 50-55). Hence provided all the samples in a building have estimated felling-date ranges broadly in agreement with each other, so that they appear to have been felled as a group, then this should give an accurate estimate of the period when the structure was built, or soon after (Laxton *et al* 2001, figure 8 and pages 34-5 where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storing before use or if there is evidence the oak came from abroad (eg Baltic boards), then some allowance has to be made for this.

6. ***Master Chronological Sequences.*** Ultimately, to date a sequence of ring widths, or a site sequence, we need a master sequence of dated ring widths with which to cross-match it, a Master Chronology. To construct such a sequence we have to start with a sequence of widths whose dates are known and this means beginning with a sequence from an oak tree whose date of felling is known. In 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 (1988), but the components it contains are shown here in the form of a bar diagram. As can be seen, it is well replicated in that for each year in this period there are several sample sequences having widths for that year. The master is the average of these. This master can now be used to date oak from this area and from the surrounding areas where the climate is very similar to that in the East Midlands. The Laboratory has also constructed a master for Kent (Laxton and Litton 1989). The method the Laboratory uses to construct a master sequence, such as the East Midlands and Kent, is completely objective and uses the Litton-Zainodin grouping procedure (Laxton *et al* 1988). Other laboratories and individuals have constructed masters for other areas and have made them available. As well as these masters, local (dated) site chronologies can be used to date other buildings from nearby. The Laboratory has hundreds of these site sequences from many parts of England and Wales covering many short periods.

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

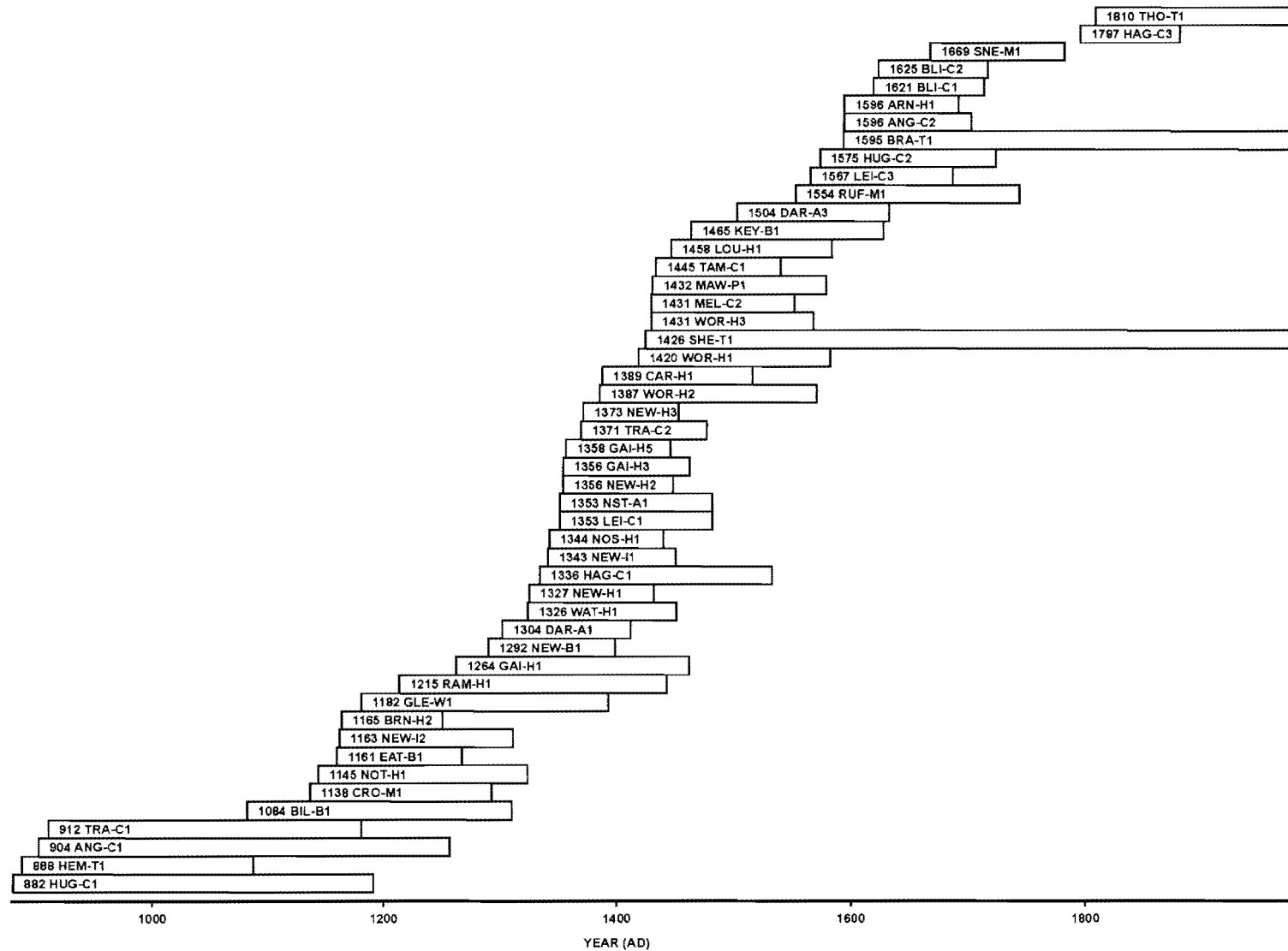
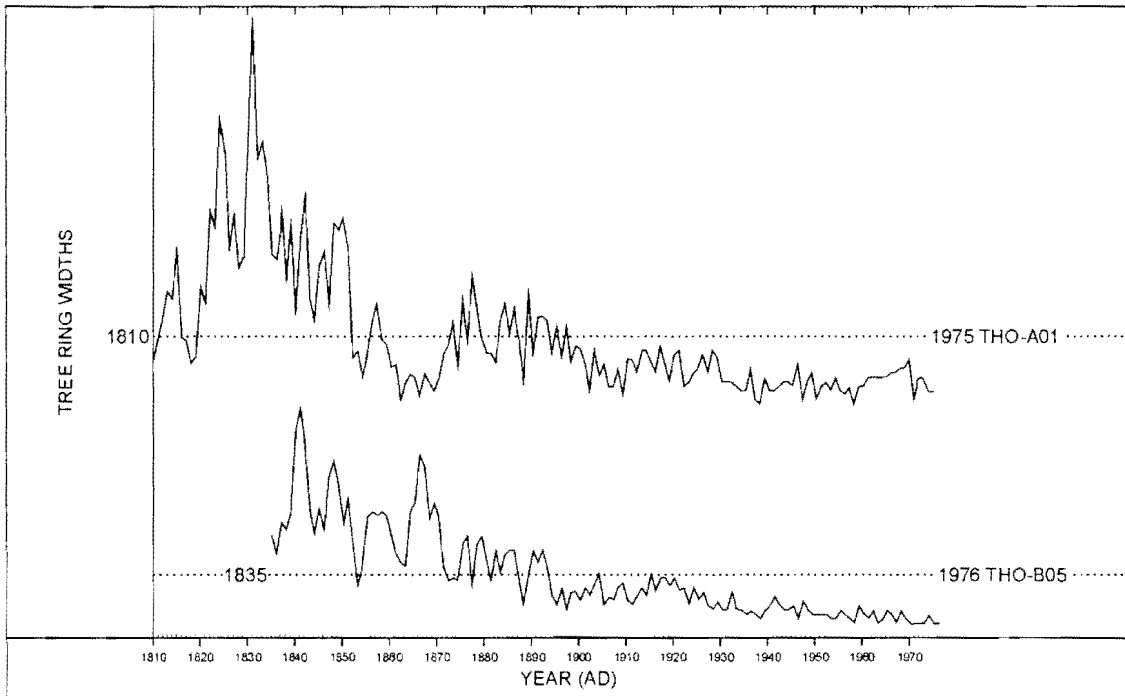


Fig. 6 Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

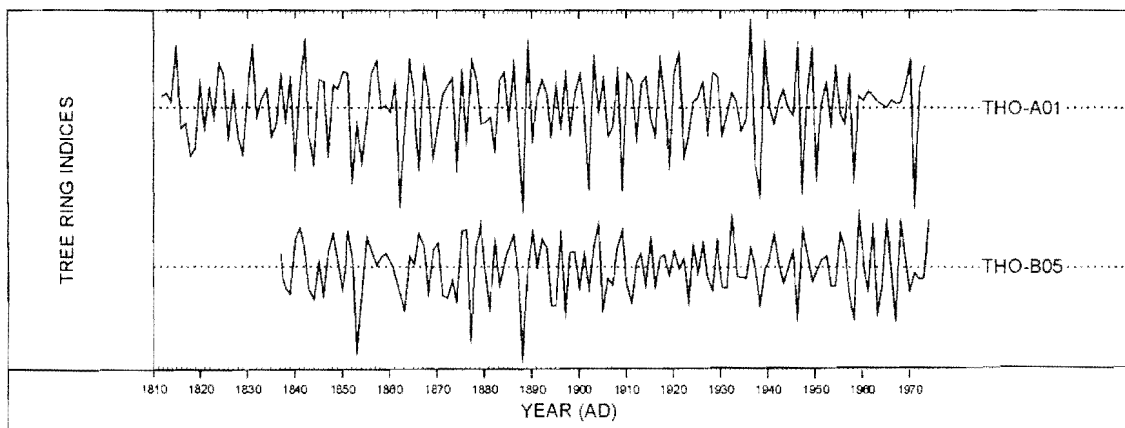


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

Fig 7. (b) The *Baillie-Pilcher* indices of the above widths. The growth-trends have been removed completely.

REFERENCES

- Baillie, M G L, and Pilcher, J R, 1973, A simple cross-dating program for tree-ring research, *Tree-Ring Bulletin*, **33**, 7-14
- English Heritage, 1998 *Dendrochronology; Guidelines on Producing and Interpreting Dendrochronological Dates*, London
- Hillam, J, Morgan, R A, and Tyers, I, 1987, Sapwood estimates and the dating of short ring sequences, *Applications of tree-ring studies*, BAR Int Ser, **3**, 165-85
- Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1984-95, Nottingham University Tree-Ring Dating Laboratory Results, *Vernacular Architecture*, **15-26**
- Hughes, M K, Milson, S J, and Legett, P A, 1981 Sapwood estimates in the interpretation of tree-ring dates, *J Archaeol Sci*, **8**, 381-90
- Laxon, R R, Litton, C D, and Zainodin, H J, 1988 An objective method for forming a master ring-width sequence, *P A C T*, **22**, 25-35
- Laxton, R R, and Litton, C D, 1988 *An East Midlands Master Chronology and its use for dating vernacular buildings*, University of Nottingham, Department of Archaeology Publication, Monograph Series III
- Laxton, R R, and Litton, C D, 1989 Construction of a Kent Master Dendrochronological Sequence for Oak, AD 1158 to 1540, *Medieval Archaeol*, **33**, 90-8
- Laxon, R R, Litton, C D, and Howard, R E, 2001 *Timber; Dendrochronology of Roof Timbers at Lincoln Cathedral*, English Heritage Research Transactions, **7**
- Litton, C D, and Zainodin, H J, 1991 Statistical models of Dendrochronology, *J Archaeol Sci*, **18**, 29-40
- Miles, D W H, 1997 The interpretation, presentation and use of tree-ring dates, *Vernacular Architecture*, **28**, 40-56
- Pearson, S, 1995 *The Medieval Houses of Kent, An Historical Analysis*, London
- Rackham, O, 1976 *Trees and Woodland in the British Landscape*, London