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DANDRA GARTH, GARSDALE, CUMBRIA
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

INTERVENTION AND ANALYSIS

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SUMMARY

Analysis undertaken on samples from a number of different areas at Dandra Garth resulted in the dating of site sequence DNDRSQ01, which contains 32 samples, to the period AD 1373–1635.

The earliest timbers identified are a purlin (thought to be reused from the original roof), dated to AD 1565–90, and a floorboard from the attic dated to AD 1586–95. Other floorboards have *terminus post quem* felling dates ranging from AD 1477 to AD 1600.

The first- and attic-floor frames contain timber dated to AD 1633 and AD 1635 and are thought to be broadly contemporary with the kitchen lintel (AD 1628–53) and partitioning (AD 1624–43).

Two further site sequences are undated.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Laboratory would like to thank Frances and Darren Lumber, the owners of Dandra Garth, for showing us around their home, for their hospitality, and for the report cover photograph. Peter Ryder kindly allowed us access to his report on the building, on which the following introduction is largely based, and Paul Crosby, architect, provided the drawings used to locate samples. Thanks are also given to Cathy Tyers and Shahina Farid of the English Heritage Scientific Dating Team for commissioning the analysis, as well as their advice and assistance throughout the production of this report.

ARCHIVE LOCATION

Cumbria Historic Environment Record
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DATE OF INVESTIGATION

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CONTENTS

INTRODUCTION

Dandra Garth is a Grade II* listed farmhouse, situated in Garsdale in the Yorkshire Dales National Park (Figs 1–3). It is an inverted 'T' shaped plan (Fig 4) with a main east-west aligned range of three storeys and three bays, and with a smokehood in the western end of the attic. Behind this main range, set slightly off-centre, is a short, north block which is thought to have been a gabled wing originally but now has a catslide roof continuous with that of the main building. Both ranges are built of roughly-coursed and roughly-squared stone under a low-pitched flagged roof.

Dandra Garth is believed to be 'one of the oldest houses in the dale, dating at least from the early 1500s, and probably much earlier' (www.garsdale.info), with the north block thought, on structural grounds, to be the oldest part. The main range with its original upper-cruck roof has been described as broadly seventeenth or early eighteenth century in character and, in his assessment of the building, Peter Ryder found nothing to suggest a date from before the seventeenth century (Ryder 2012). In the eighteenth/early nineteenth century the side walls were raised and the original heather-thatched roof replaced by the present stone flag one. Other alterations included the replacement of the smokehood at the west end with an internal stone stack servicing ground- and first-floor fireplaces.

Main range

At ground-floor level the house is divided by a passage, to the west of which is the living room with a mural staircase in the north-east corner, and to the east is what was the parlour but is now kitchen and dairy (Fig 4). In the kitchen, over the fireplace mantelpiece, is a plaster panel depicting a lion amongst leaves thought to commemorate a visit by James I of England in April AD 1603.

Roof

The extant roof is of three trusses, the easternmost one (truss 3) is of softwood whilst the other two are oak. The trusses consist of principal rafters, tiebeams, and slightly arched collars (the collar of truss 2 is no longer *in situ* but lies amongst other beams to one side). There is a double row of purlins to each side and a ridge board (Fig 5). This present roof replaced an earlier upper-cruck one; the cut off remains of two of these blades can still be seen at first-floor level and in the attic. Other roof timbers have redundant mortices and are thought to represent reused timber from the original roof; the chimney lintel can also be seen to have a cut out, perhaps for a lap joint, and may again be from the original roof (Fig 6).

Floor frames

The first-floor frame is visible from ground-floor level and can be seen to consist of, in the living room, two, heavy, main north-south, chamfered beams. The north end of beam 02 (Fig 4) is carried by the lintel of the door into the mural stair. In the kitchen there is a third main beam (03) with chamfers and stepped stops, the south end of which rests on a heavy lintel over the window. Either side of this main beam (03) are a series of smaller common joists, some of which are chamfered and others left square (Fig 7). The attic-floor frame is partly visible in the attic where floorboards are loose or missing and again consists of main beams and common joists, some of which are chamfered and some simply squared (Fig 8).

Floorboards

The first floor has broad, oak floorboards pegged to the joints beneath. It was noted that the joints between sections of boarding did not appear to have a relationship with the partitioning above (Ryder 2012). In the attic there are further floorboards of varying character, although some do resemble those seen below, others are still pegged in position and some are loose (Fig 9).

Partitions

At first-floor level there are two transverse plank-and-muntin partitions (Figs 10 and 13) which would have divided the space into three rooms, with a third longitudinal partition creating a corridor. The northern part of the eastern partition has been removed and a later partition installed, dividing the eastern room into two. The older partitions consist of moulded studs, grooved, to take intermediate planks.

SAMPLING

A dendrochronological survey was requested by Diane Green, English Heritage, to inform listed building consent for repair and possible replacement of the roof. It was hoped that by establishing the date of the primary roof construction and any earlier timber elements, whether reused, *ex situ* or *in situ*, that it would be possible to identify earlier forms of the farmhouse. Independent dating evidence would also add to the overall understanding of its historic development and hence inform significance and its future care.

Forty-one timbers from various areas of the building were sampled by coring, four planks from one of the partitions had *in situ* readings taken from them, and samples in the form of thin cross-sectional slices were taken from eleven loose floorboards in the attic. Each sample was given the code DND-R and numbered 1–56. One of the partition planks had a slight crack, disrupting the growth pattern, and so it was not possible to measure this plank in a single-run. Therefore, the beginning of this plank, up to the crack, was measured first (DND-R45), followed by a new set of measurements after the crack to the end of the plank (DND-T45). The location of measured *in situ* samples and partition planks was noted at the time of sampling and marked on Figures 11–15. Further details relating to the samples can be found in Table 1.

ANALYSIS AND RESULTS

Six samples, two from the extant roof (DND-R05 and DND-R06), three from lintels (DND-R15, DND-R17, and DND-R18), and one from the first-floor frame (DND-R26) had too few rings for secure dating and so were discarded prior to measurement. The remaining 46 cores/slices were prepared by sanding and polishing and their growth-ring widths measured; the data of these measurements, and the *in situ* measurements taken from the partition planks, are given at the end of the report. All samples were then compared with each other by the Litton/Zainodin grouping programme (see Appendix), resulting in 36 samples matching to form three groups.

Firstly, 32 samples (including the inner and outer sets of measurements from a single partition plank, DND-R45 and DND-T45) from all areas matched each other and were combined at the relevant offset positions to form DNDRSQ01, a site sequence of 263 rings (Fig 16). This site sequence was compared against a series of relevant reference chronologies for oak where it was found to span the period AD 1373–1635. The evidence for this dating is given in Table 2.

Two samples, one from a reused roof timber and one from a chimney lintel in the attic, grouped to form DNDRSQ02, a site sequence of 60 rings (Fig 17). This site sequence was compared against a series of relevant reference chronologies for oak but could not be securely matched and so remains undated.

Finally, two further samples from the roof matched each other and were combined to form DNDRSQ03, a site sequence of 102 rings (Fig 18). Attempts to date this site sequence and the remaining 15 ungrouped samples were unsuccessful and all remain undated.

INTERPRETATION

Tree-ring analysis has resulted in the successful dating of 31 timbers (32 samples) from all areas targeted. To aid interpretation each area is dealt with separately below and illustrated in Figure 19. Felling date ranges have been calculated using the estimate that mature oak trees in this region have 15–40 sapwood rings.

Roof

Only one of the samples taken from the roof has been successfully dated. Sample DND-R08, taken from a purlin, has a last-measured ring date of AD 1550 (the heartwood/sapwood boundary) and an estimated felling date within the range AD 1565–90. The timber represented is thought to be reused in its present location from the original roof.

Lintels

Only one lintel has been dated; sample DND-R14, taken from the lintel over the kitchen window has a last-measured ring date of AD 1613 and is estimated to have been felled in AD 1628–53.

First-floor frame

Five of the samples taken from the timbers of the first-floor frame have been dated, three of which have complete sapwood. Two of these three (DND-R22 and DND-R24), have the last-measured ring date of AD 1633, the felling date of the timbers represented. The last-measured ring date of the third sample (DND-R28) with complete sapwood is AD 1635, the felling date of the timber represented. Sample DND-R27 has the heartwood/sapwood boundary ring date of AD 1615, giving an estimated felling date for the timber represented to within the range AD 1630–55, consistent with either an AD 1633 or AD 1635 felling. The final dated sample from the first-floor frame (DND-R23), does not have the heartwood/sapwood boundary ring and so an estimated felling date range cannot be calculated for it except to say, with a last-measured heartwood ring date of AD 1549, this would be AD 1565 at the earliest. However, this sample matches samples DND-R31 and DND-R33 at values of t=11.0 and t=11.9 respectively, which does suggest that they are all cut from the same tree and would, therefore, have the same felling date (see below).

Attic-floor frame

Nine samples taken from timber of this floor frame have been dated. Sample DND-R30 has complete sapwood and the last-measured ring date of AD 1633, the felling date of the timber represented. Two other samples (DND-R29 and DND-R33) both have the heartwood/sapwood boundary ring, which is broadly contemporary and suggestive of a single felling. The average heartwood/sapwood boundary of these two samples is AD 1603, giving an estimated felling date range for the two timbers represented (allowing for sample DND-R29 having a last-measured ring date of AD 1630 with incomplete sapwood), of AD 1631–43, consistent with a felling of AD 1633.

None of the other dated attic-floor frame samples have the heartwood/sapwood boundary but with last-measured heartwood ring dates ranging from AD 1484 (DND-R32) to AD 1598 (DND-R34) it is possible that these were also felled in AD 1633. Furthermore, one of these samples DND-R31, matches DND-R33 (felled AD 1631–43) at a value of *t*=16.4 and, therefore, is likely to have been cut from the same tree and would have been felled at the same time.

Floorboards

Samples were taken from eleven of the loose floorboards from the attic; of these, nine have been dated. Only sample DND-R47 has the heartwood/sapwood boundary ring; the date of this is AD 1555, which, when the last-measured ring date of this sample (AD 1585) is taken into consideration gives an estimated felling date range of AD 1586–95 for the timber represented. The last-measured heartwood ring dates of the other dated samples vary from AD 1462 (DND-R56) to AD 1585 (DND-R53), giving *terminus post quem* felling dates ranging from AD 1477 to AD 1600. It is possible for all but sample DND-R53 to have also been felled in AD 1586–95, however, equally they could represent different felling/s.

Partitions

Two of the top-beams associated with the partitioning, and four of the planks have been dated. Only one of these (DND-R40), taken from a top rail, has the heartwood/sapwood boundary ring, the date of which is AD 1603, giving an estimated felling date range for the timber represented of AD 1624–43. This allows for the sample having a last-measured ring date of AD 1623 with incomplete sapwood.

The rest of the dated samples do not have the heartwood/sapwood boundary and so estimated felling date ranges cannot be calculated for them, except to say, with last-measured heartwood ring dates varying from AD 1515 (DND-R43) to AD 1597 (DND-R39), this would give *terminus post quem* felling dates ranging from AD 1530 to AD 1612 making it possible for all of them to have been felled in AD 1624–43.

DISCUSSION

Although Dandra Garth is thought of locally as being of some antiquity, prior to the tree-ring dating being undertaken there was thought to be nothing structurally to prove a date before *c* AD 1700. The dendrochronology has now identified two phases of felling, both of which pre-date AD 1700.

The earliest felling is represented by a purlin, believed to be reused from the original roof, dated to AD 1565–90 and a floorboard found in the attic which dates to AD 1586–95. It is likely that these two timbers are contemporary and relate to a single programme of work, undertaken in the final decades of the sixteenth century, and thus providing evidence that the main range is potentially earlier than previously thought (seventeenth or early eighteenth century). These two samples match each other well at *t*=8.0 (which is a higher value than any other match), pointing to the same woodland source being utilised for both timbers, further supporting the suggestion that they belong to the same programme of felling.

It is unfortunate that an estimated felling date range could only be calculated for one of the floorboards, with the others having *terminus post quem* felling dates only. With the exception of sample DND-R53, it is possible that the rest of the floorboards also represent trees felled in AD 1586–95. However, this cannot be said with confidence and given the fact that DND-R53 is almost certainly from a tree felled after this date (unless one floorboard is cut from a tree with less than the average number of sapwood rings, or the other is cut from one with more), it is possible that more than one phase of work is represented within the floorboards.

The majority of the dated timber is somewhat later, belonging to the first half of the seventeenth century. Timbers of the first- and attic-floor frames have been dated to AD 1633 and AD 1635. The lintel over the kitchen window has been dated to AD 1628–53. Given the relationship between this lintel and the first-floor frame (one of the main beams rests on it) and that its felling date range is consistent with it also having been felled in AD 1633 or AD 1635, this lintel is likely to be contemporary with the floor frames.

The top rail of one of the partitions has been dated to AD 1624–43, consistent with this beam also having been felled in the AD 1630s. The rest of the dated samples taken from the partitions have *terminus post quem* felling dates ranging from AD 1530 to AD 1612, making it possible that they were also felled in AD 1624–43. In contrast to the dated floorboards, which were *ex situ* and hence could not be associated absolutely to each other, the partitions are intact and it may be safer, in this case, to assume all timbers are contemporary.

The lack of an apparent relationship between the position of the partitioning and the floorboards below them had raised the possibility that these two elements were of different phases, with the partitions being slightly later. Indeed, it is now known that at least one of the floorboards (represented by sample DND-R47) belongs to the late-sixteenth century and at least one of the partition top rails is seventeenth century (AD 1624–43).

With a *t*-value match of 16.4, samples DND-R31 and DND-R33, both taken from joists of the attic-floor frame, are almost certainly cut from the same tree, despite DND-R31 having a last-measured ring date (AD 1487) substantially earlier than that of DND-R33 (AD 1616). This suggests that DND-R31 is the inner portion of a very long-lived tree (more than 200 years old at felling), whilst DND-R33 is the outer portion. The *t*-values of sample DND-R23 (from the first-floor frame), against these two samples (above), makes it likely to be another inner portion of the same tree (end date AD 1543).

It is unfortunate that more of the samples taken from timbers thought to be reused from the original roof could not be dated as this might have added support for a primary phase in the late-sixteenth century. Undated site sequence DNDRSQ02 contains DND-R10, taken from a purlin, and DND-R20, from the lintel over the chimney. Both of these timbers were thought to be reused from the earlier roof and although this cannot be proved or even their date demonstrated, it can be said that, by looking at their relative heartwood/sapwood ring positions (Fig 17), they are likely to have been felled at the same time and hence are probably from the same structure. Similarly, undated site sequence DNDRSQ03, containing a sample from one of the *in situ* blades (a remnant from the earlier roof) and a principal rafter in the extant roof demonstrates that these timbers are of the same felling (again it is unknown when this was) thus demonstrating the likelihood that timbers from the upper cruck roof were indeed utilised within the present roof.

The dendrochronology has demonstrated that the majority of the extant internal timber fabric is dated to the first half of the seventeenth century but that there is also evidence, on the basis of only two timbers presently, for an earlier phase dating to the last decades of the sixteenth century. This suggests a late sixteenth-century building, heavily modified, with the insertion of floors and partitioning, in the AD 1630s.

Analysis of samples from Dandra Garth produced a single dated site sequence which contained samples from all areas and represented timber from both the late-sixteenth and seventeenth centuries. Generally, the level of cross-matching seen between samples is good suggesting that the same source of timber was used for the different elements and that this source was utilised during both phases of work. Given that DNDRSQ01 matches most highly against Nether Levens Hall in Cumbria (Table 2) it is thought that this woodland source is likely to be relatively local.

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TABLES

Table 1: Details of samples from Dandra Garth, Garsdale, North Yorkshire

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Roof						
01	North *in situ* blade	66	--	----	----	----
02	South *in situ* blade	74	h/s	----	----	----
03	North principal rafter, truss 1	43	01	----	----	----
04	South principal rafter, truss 1 - reused	102	h/s	----	----	----
05	Tiebeam, truss 1	NM	--	----	----	----
06	South principal rafter, truss 2	NM	--	----	----	----
07	Tiebeam, truss 2	84	h/s	----	----	----
08	South upper purlin, west end truss 1 - reused	87	h/s	1464	1550	1550
09	South upper purlin, truss 1–2	41	h/s	----	----	----
10	South lower purlin, west end to truss 2	60	01	----	----	----
11	North upper purlin, west end truss 1 - reused	81	01	----	----	----
12	North lower purlin, west end truss 2- reused	45	h/s	----	----	----
13	North common rafter 6, bay 1	45	h/s	----	----	----
Lintels						
14	Kitchen, W03	186	h/s	1428	1613	1613
15	Living room, blocked doorway to north range	NM	--	----	----	----
16	Living room stairway, outer lintel	88	16C	----	----	----
17	Stairway, middle lintel	NM	--	----	----	----
18	Bedroom 1, W08	NM	--	----	----	----
19	Bedroom 3, W10	58	01	----	----	----
20	Attic chimney stack, - reused	51	h/s	----	----	----
First-floor frame						
21	Beam 01	63	18	----	----	----
22	Beam 02	46	15C	1588	1618	1633
23	Beam 03	144	--	1406	---	1549
24	Kitchen, joist 2 east	66	16C	1568	1617	1633

25	Kitchen, joist 3 east	54	--	----	----	----
26	Kitchen, joist 4 east	NM	--	----	----	----
27	Kitchen, joist 1 west	104	08	1520	1615	1623
28	Kitchen, joist 3 west	97	20C	1539	1615	1635
Attic floor frame						
29	Beam 04	97	36	1534	1594	1630
30	Beam 07	101	22C	1533	1611	1633
31	Joist 9, bay 1	86	--	1402	----	1487
32	Joist 5, bay 1	86	--	1399	----	1484
33	Joist 3, bay 1	166	05	1451	1611	1616
34	Joist 1, bay 2	147	--	1452	----	1598
35	Joist 3, bay 2	97	38C	----	----	----
36	Joist 8, bay 2	77	--	1468	----	1544
37	Joist 5, bay 3	88	--	1448	----	1535
38	Joist 10, bay 3	97	--	1416	----	1512
Plank & muntin screens						
39	Beam 05, plank & muntin top rail	70	--	1528	----	1597
40	Beam 06, plank & muntin top rail	90	20	1534	1603	1623
41	East-west partition, muntin top rail	64	--	1521	----	1584
42	East-west partition, plank	65	--	----	----	----
43	East-west partition, plank	55	--	1461	----	1515
44	East-west partition, plank	70	--	1435	----	1504
R45	East-west partition, plank (inner section)	47	--	1404	----	1450
T45	East-west partition, plank (outer section)	69	--	1460	----	1528
Attic floorboards (*ex situ*)						
46	Floorboard	51	--	1456	----	1506
47	Floorboard	102	30	1484	1555	1585
48	Floorboard	92	--	----	----	----
49	Floorboard	61	--	1477	----	1537
50	Floorboard	152	--	1402	----	1553
51	Floorboard	75	--	----	----	----
52	Floorboard	71	--	1400	----	1470
53	Floorboard	133	--	1453	----	1585

54	Floorboard	72	--	1433	----	1504
55	Floorboard	99	--	1409	----	1507
56	Floorboard	90	--	1373	----	1462

*NM = not measured
**h/s = heartwood/sapwood boundary is the last-measured ring
C = complete sapwood retained on sample, last measured ring is the felling date

Table 2: Results of the cross-matching of site sequence DNDRSQ01 and relevant reference chronologies when the first-ring date is AD 1373 and the last-measured ring date is AD 1635

Reference chronology	*t*-value	Span of chronology	Reference
Nether Levens Hall, Kendal, Cumbria	10.3	AD 1395–1541	Arnold *et al* 2008
Auckland Castle, Bishop Auckland, County Durham	8.7	AD 1425–1698	Arnold and Howard 2013
Turton Tower, Lancashire	8.3	AD 1483–1665	Arnold and Howard 2008
Howley Hall Farm, Morley, West Yorkshire	8.0	AD 1415–1635	Arnold and Howard 2013
Bolsover Castle (Riding School), Bolsover, Derbyshire	7.9	AD 1494–1744	Arnold *et al* 2005
Hougher Hall Farm, Dutton, Lancashire	7.8	AD 1452–1550	Arnold and Howard 2012
2–4 Church Street, Leek, Staffordshire	7.8	AD 1406–1512	Arnold and Howard 2009

FIGURES

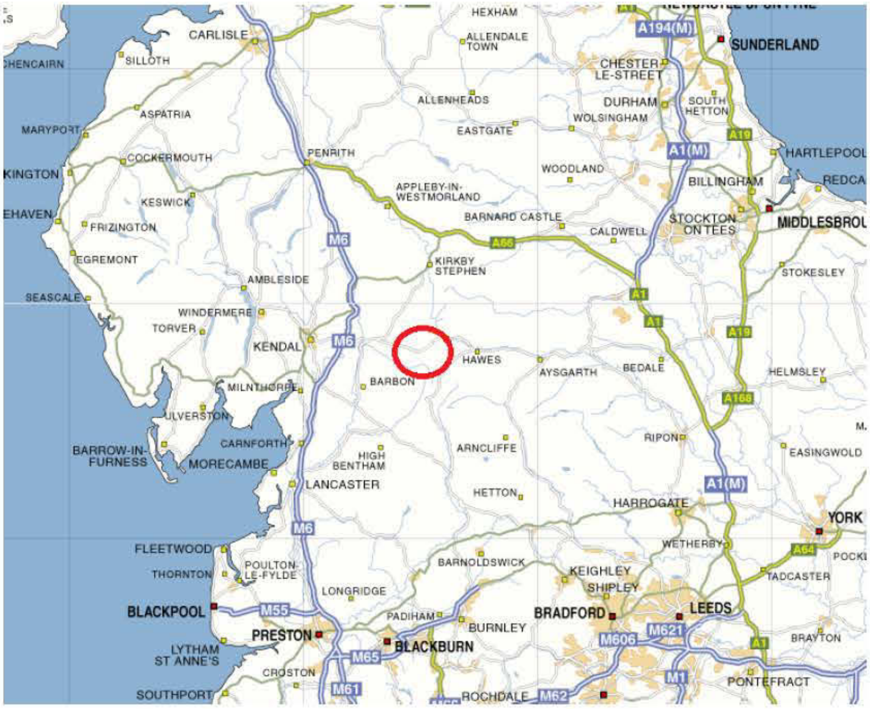

Figure 1: Map to show the general location of Dandra Garth, circled. © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

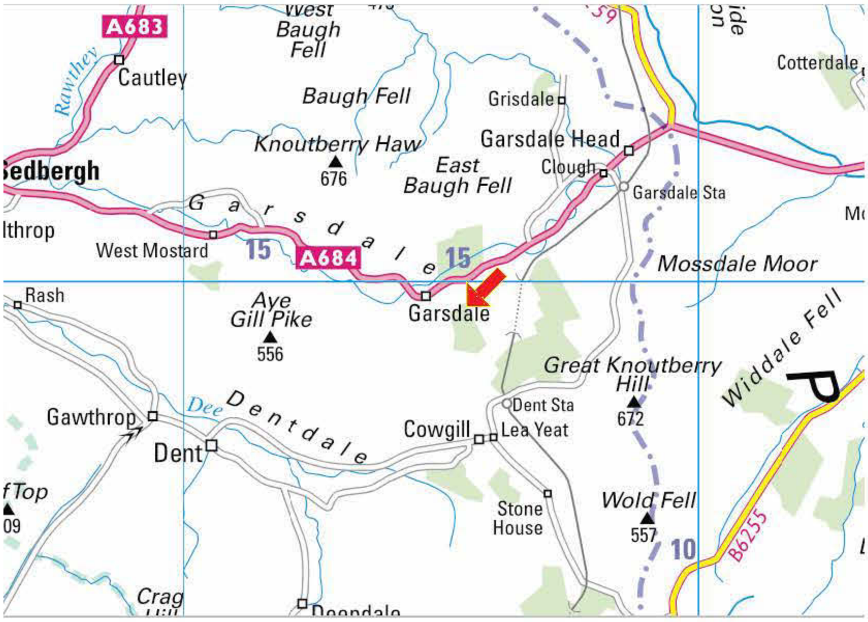

Figure 2: Map to show the general location of Dandra Garth, arrowed. © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

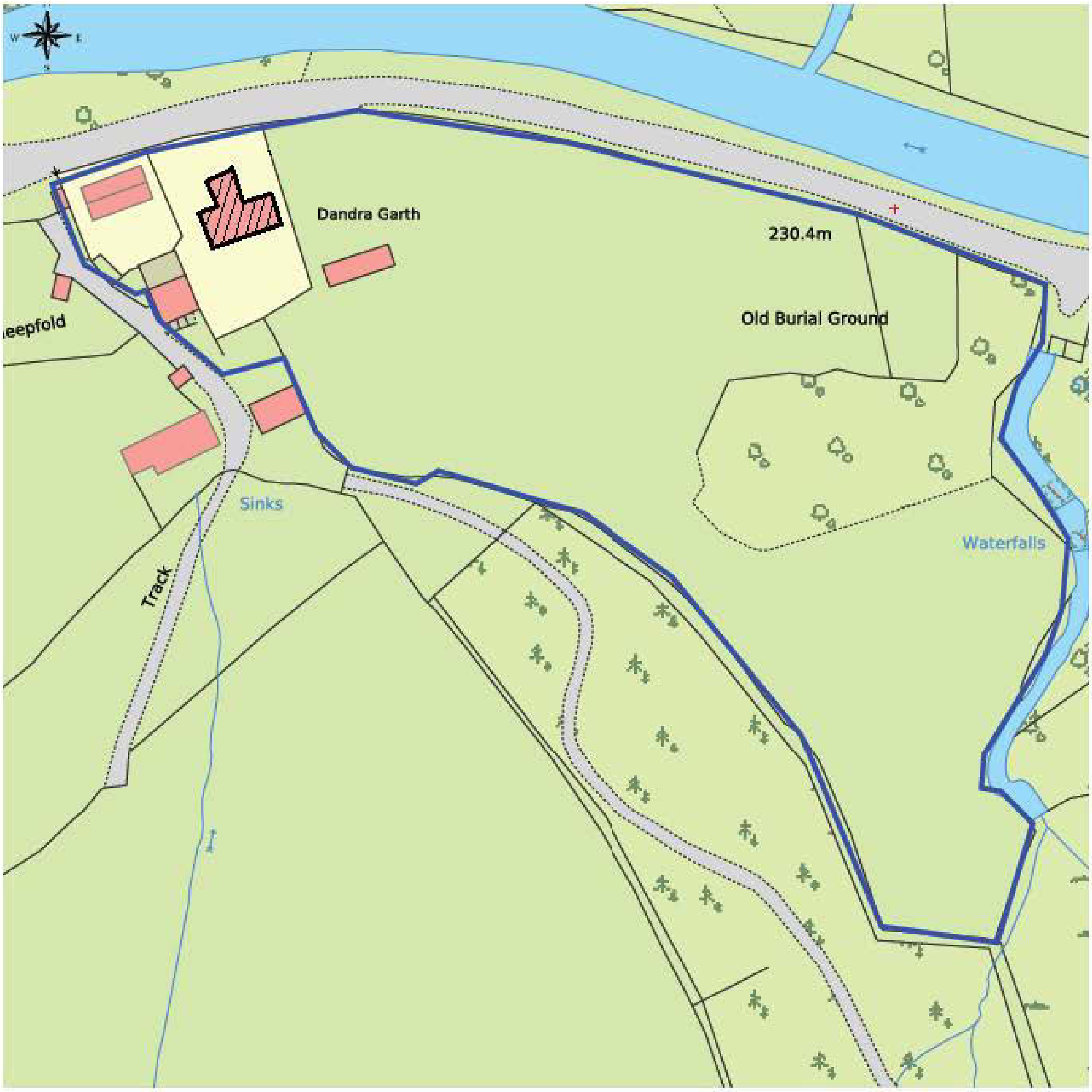

Figure 3: Map to show the location of Dandra Garth. © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

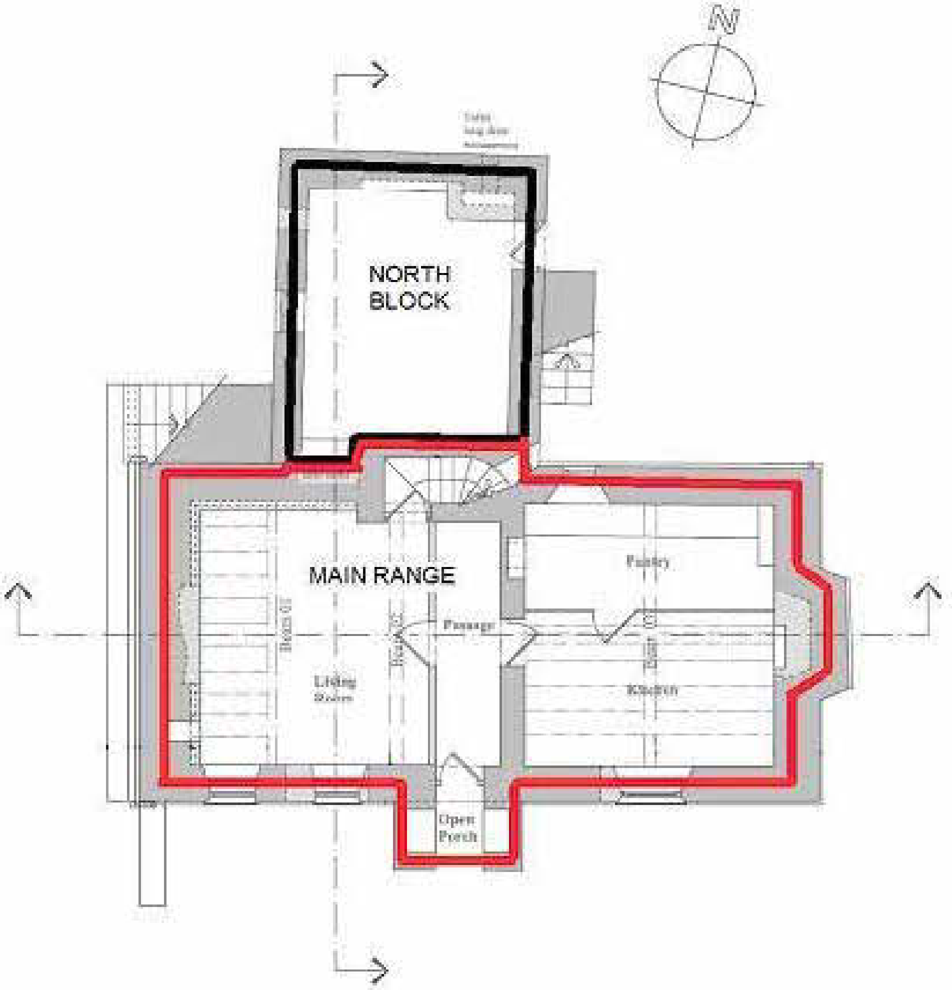

Figure 4: Plan of Dandra Garth (Paul Crosby Architect, annotated by PFR)

Figure 5: The roof, with truss 2 in the foreground, photograph taken from the west (Alison Arnold)

Figure 6: Chimney stack with timber lintel, photograph taken from the east (Alison Arnold)

Figure 7: First-floor frame, viewed from below in the kitchen, photograph taken from the north-west (Alison Arnold)

Figure 8: Attic-floor frame, viewed from above (Alison Arnold)

Figure 9: Attic floorboards, some of which can be seen to have peg holes (Alison Arnold)

Figure 10: Plank-and-muntin screen, photograph taken from the west (Alison Arnold)

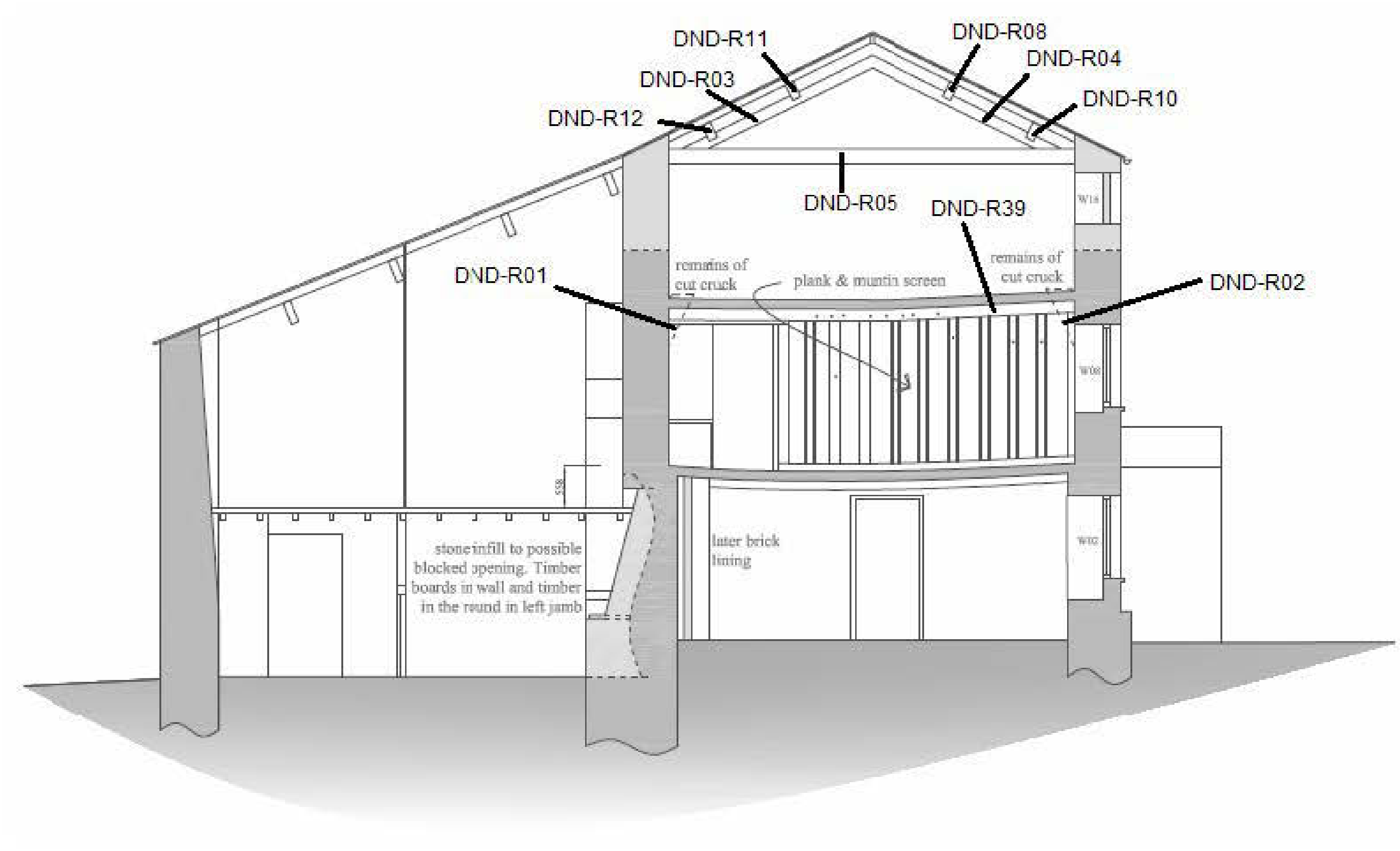

Figure 11: Section looking east, showing truss 1 and the location of samples DND-R01–05, DND-R08, DND-R10–12, and DND-R39 (Paul Crosby Architect, annotated PFR)

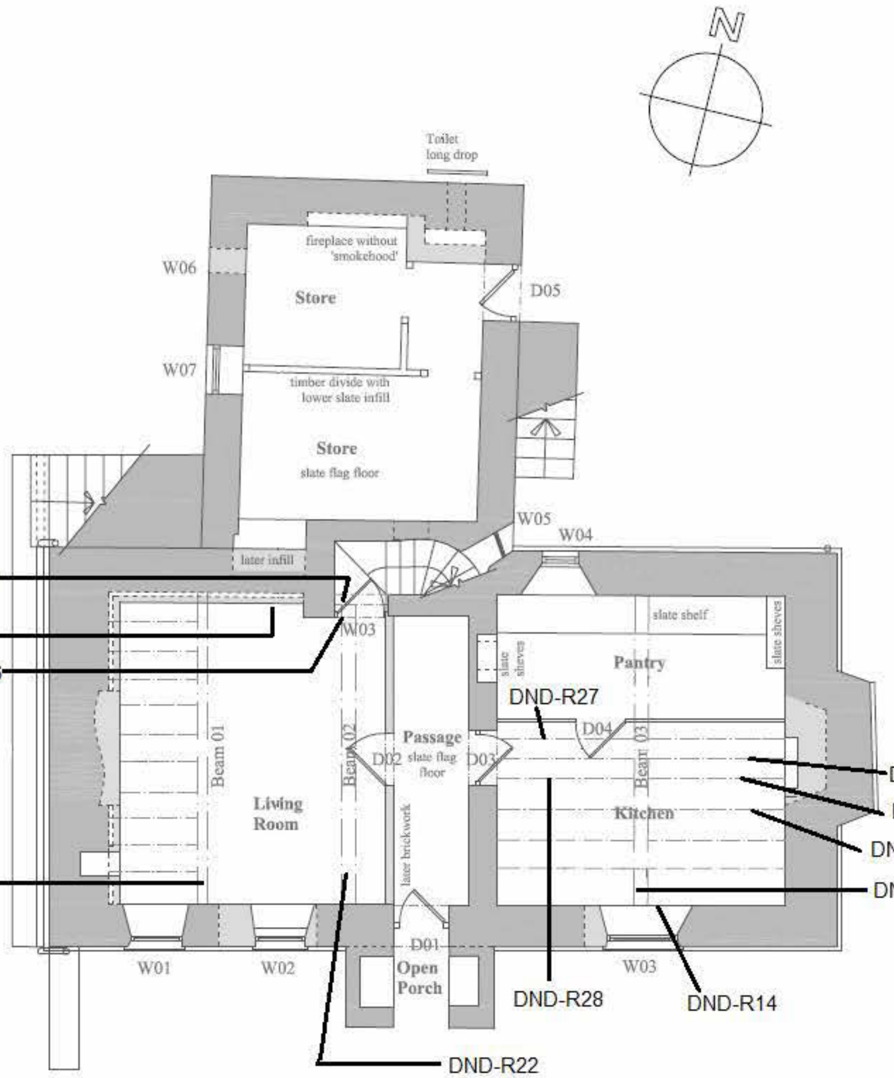

Figure 12: Ground-floor plan, showing the location of samples DND-R14–17 and DND-R21–8 (Paul Crosby Architect, annotated PFR)

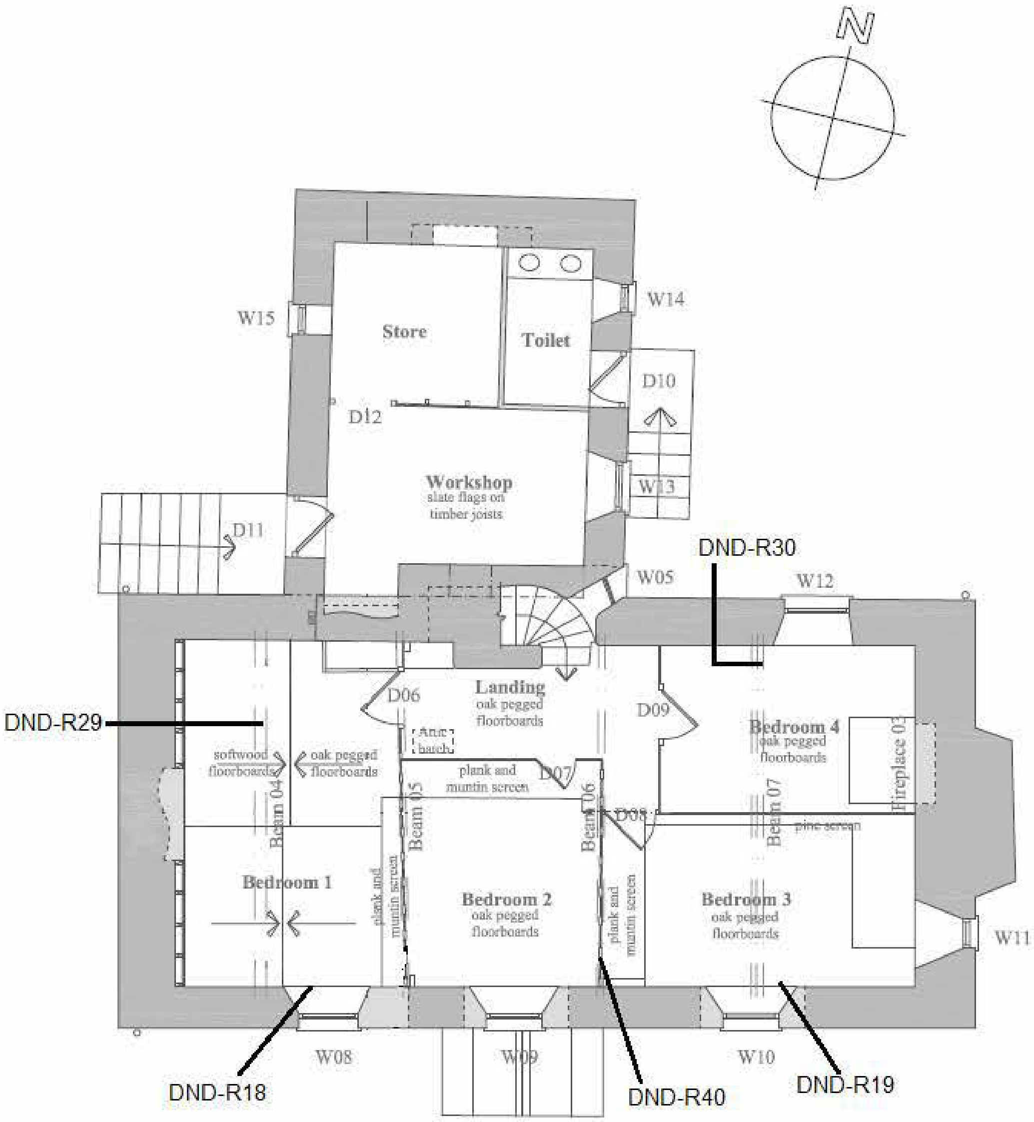

Figure 13: First-floor plan, showing the location of samples DND-R18–19, DND-R29–30, and DND-R40 (Paul Crosby Architect annotated PFR)

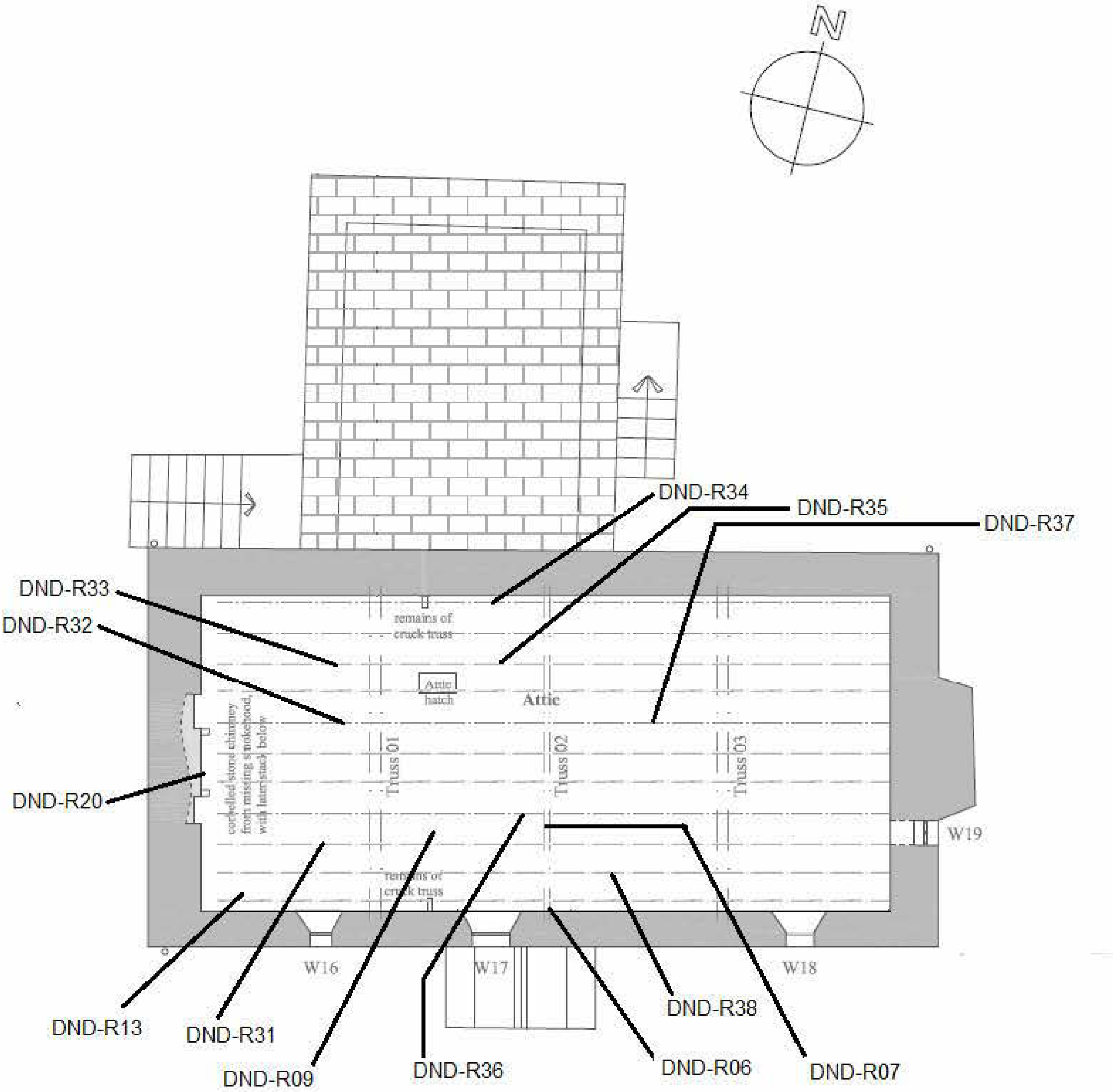

Figure 14: Attic-floor plan, showing the location of samples DND-R06–07, DND-R09, DND-R13, DND-R20, and DND-R31–8 (Paul Cosby Architect annotated PFR)

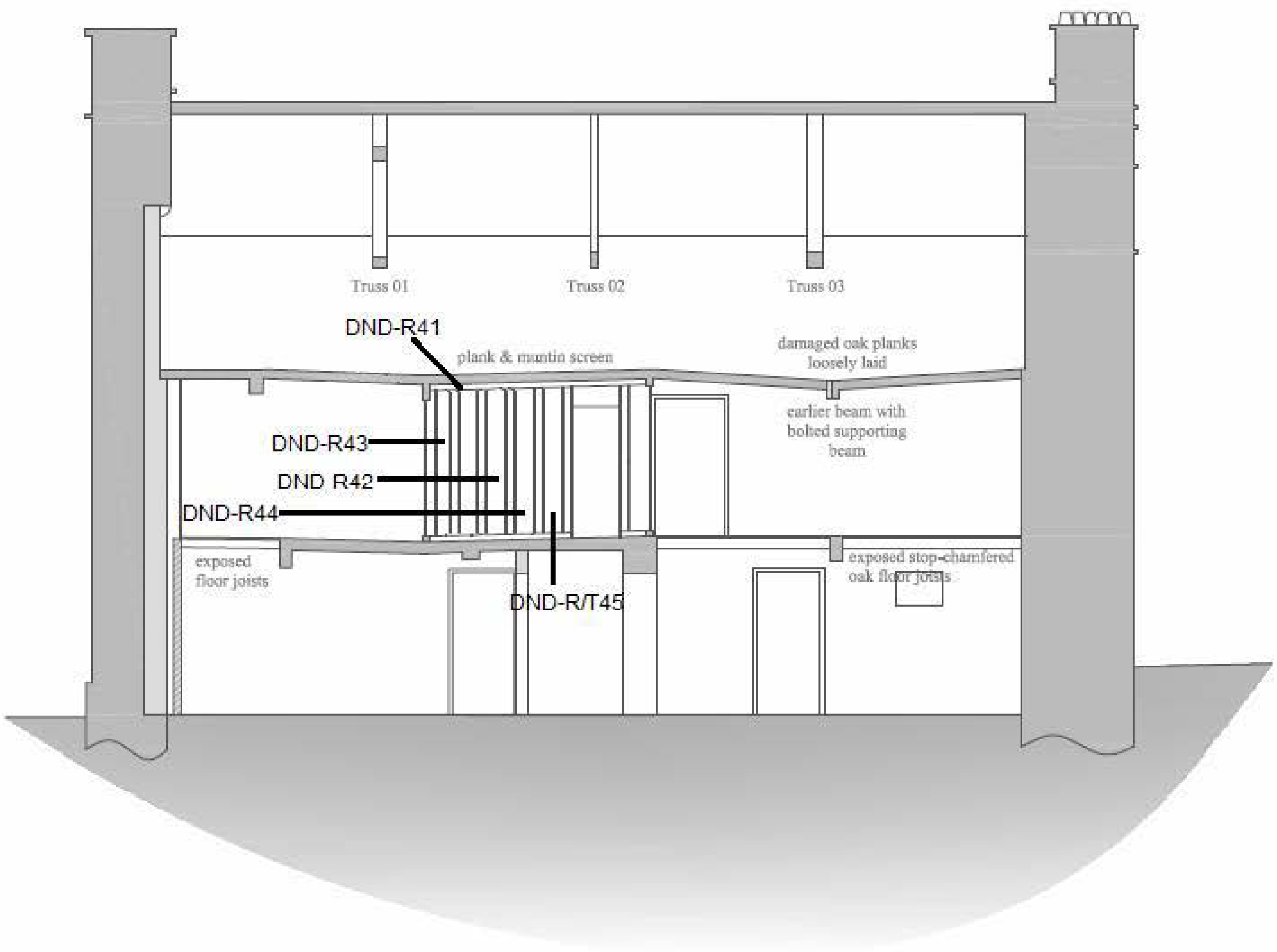

Figure 15: Long-section through the house, showing the location of samples DND-R41–5 (Paul Crosby Architect, annotated PFR)

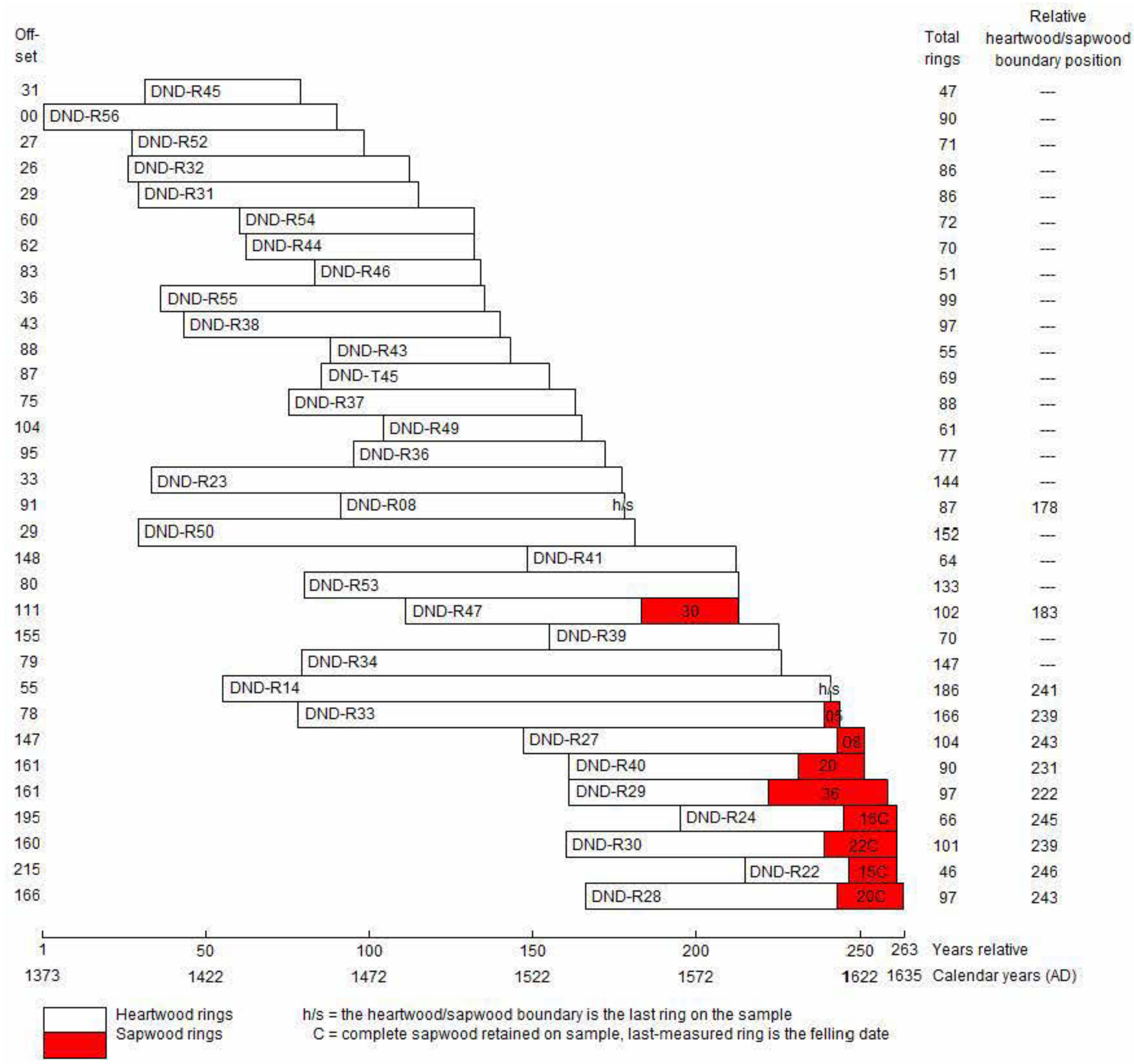

Figure 16: Bar diagram of samples in site sequence DNDRSQ01

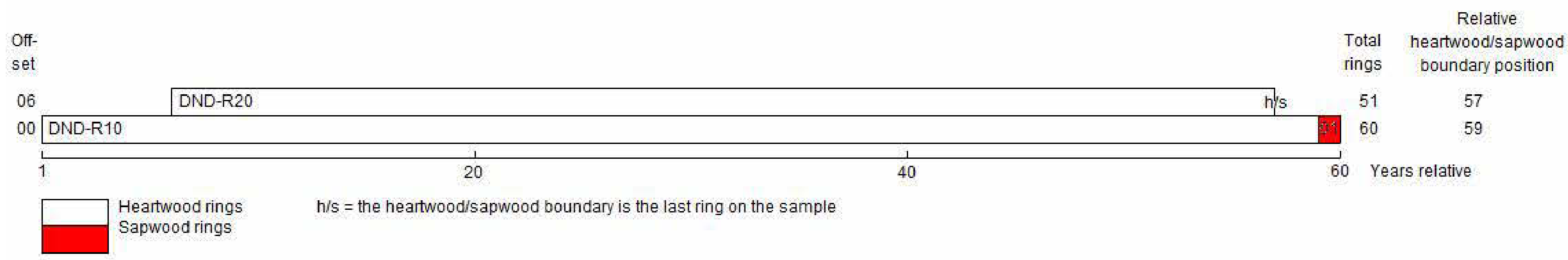

Figure 17: Bar diagram of samples in undated site sequence DNDRSQ02

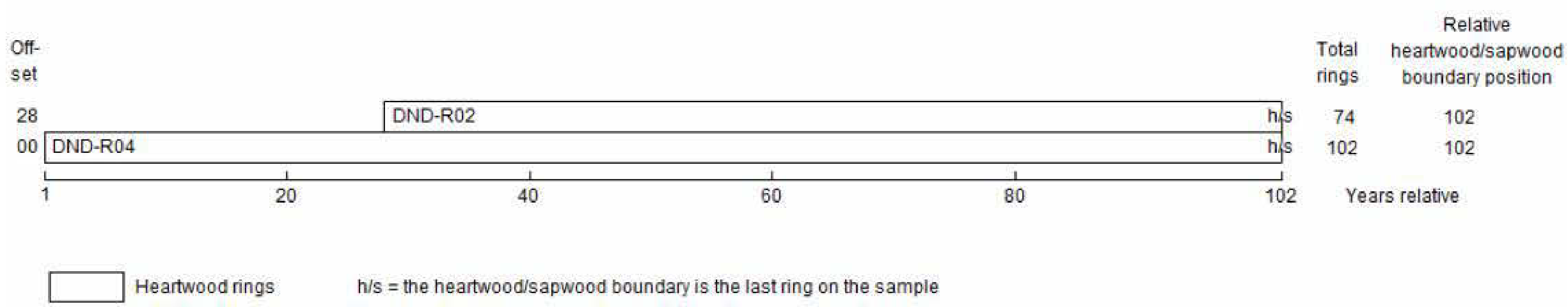

Figure 18: Bar diagram of samples in undated site sequence DNDRSQ03

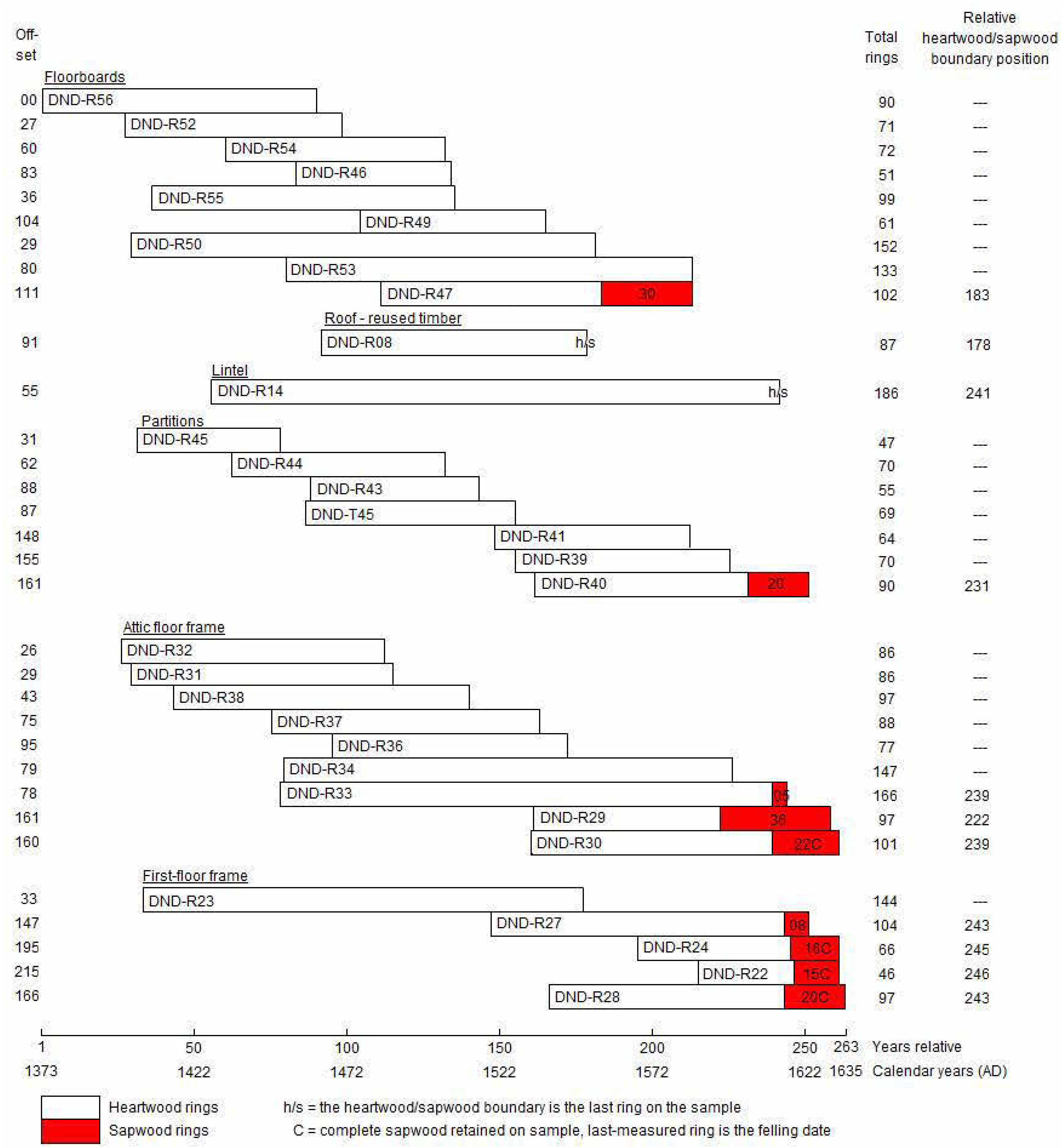

Figure 19: Bar diagram of all dated samples, sorted by area

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units with the exception of samples DND-R42–T45 which are in 0.1mm

DND-R01A 66
118 129 123 148 150 140 119 105 122 105 76 76 82 62 84 97 109 115 166 133
98 89 89 91 144 122 161 134 143 212 189 206 193 179 155 128 105 137 272 182
148 154 193 164 217 173 219 237 98 72 79 62 78 75 86 77 76 82 101 151
141 128 114 99 106 83
DND-R01B 66
121 125 126 136 144 132 127 103 119 106 78 76 76 61 89 99 110 113 174 138
119 82 76 83 141 128 171 132 145 223 191 203 198 171 135 131 107 126 234 162
148 161 194 164 208 175 219 240 98 75 78 60 80 76 92 72 80 83 95 151
143 135 113 103 113 80
DND-R02A 74
94 95 109 95 145 77 57 154 192 324 278 377 253 551 393 350 380 177 527 190
396 153 143 135 147 88 151 183 188 118 178 164 99 82 146 137 131 162 166 126
188 146 161 120 110 127 104 120 131 165 190 141 103 115 173 152 130 121 189 175
183 113 144 181 119 111 119 129 130 169 135 150 152 183
DND-R02B 74
101 86 108 92 140 76 67 163 176 327 240 332 265 504 365 341 376 170 527 182
411 136 153 137 153 86 151 178 169 117 173 180 100 73 143 156 135 167 158 122
205 162 143 117 112 123 113 116 128 167 188 137 113 102 159 155 142 130 185 183
186 121 144 187 131 105 125 137 125 161 140 159 160 177
DND-R03A 43
185 160 192 225 278 330 228 207 192 208 98 88 126 184 304 219 146 165 132 100
87 44 90 136 279 261 394 328 223 169 257 256 112 204 137 190 255 265 248 286
350 168 220
DND-R03B 43
202 153 273 216 288 315 234 188 202 221 102 83 139 182 307 216 146 161 135 102
87 43 93 137 276 264 377 325 210 165 247 254 112 199 152 186 251 249 250 280
351 173 208
DND-R04A 102
194 164 146 124 169 141 151 202 163 161 151 127 155 154 127 238 229 136 186 159
172 307 302 338 277 329 238 179 87 63 78 41 92 41 36 108 115 143 162 191
140 213 213 150 113 68 157 180 182 151 162 162 154 88 106 86 112 94 107 108
85 83 90 91 65 89 64 85 127 114 91 67 69 122 113 105 176 187 173 113
136 107 167 141 158 186 264 210 208 184 228 214 236 101 117 128 112 220 170 147
134 208
DND-R04B 102
185 167 144 114 170 135 156 185 171 163 158 120 152 156 120 237 235 126 196 162
162 312 304 340 277 324 243 184 76 71 74 39 91 50 40 111 110 144 157 201
131 215 215 144 119 79 152 188 185 150 165 157 154 96 104 89 112 91 111 110
81 94 97 72 77 78 74 84 114 118 82 70 78 117 111 108 175 185 178 111
142 102 168 146 155 184 262 210 207 180 231 214 234 98 130 121 123 215 161 162
150 206
DND-R07A 84
85 98 96 130 114 135 63 95 93 89 86 96 86 108 96 77 72 71 54 29
35 51 67 82 82 81 82 73 108 81 68 61 57 60 44 67 59 53 77 76
70 52 64 55 52 54 58 82 90 82 108 94 84 104 112 197 121 118 136 139
149 148 140 156 157 162 92 172 174 127 148 178 166 164 192 183 228 183 149 168

175 223 222 178
DND-R07B 84
85 105 102 113 111 124 71 101 100 89 101 95 78 115 88 78 72 67 61 34
36 52 60 78 80 87 89 77 105 69 66 52 42 39 35 63 52 52 89 70
72 49 67 54 49 59 63 79 84 72 98 84 93 99 108 194 128 115 135 139
146 148 139 155 155 171 94 165 172 129 148 180 163 160 185 198 236 196 147 172
170 228 222 144
DND-R08A 87
104 142 219 206 190 134 106 110 94 89 104 109 119 106 56 37 46 34 34 34
48 50 56 73 52 73 80 61 49 46 64 94 106 80 96 76 62 48 34 44
73 79 96 129 94 89 114 108 109 75 82 95 108 81 84 68 50 70 93 83
57 89 88 79 71 75 64 80 80 76 79 95 82 76 57 61 55 53 52 80
71 62 72 72 74 97 57
DND-R08B 87
116 145 220 208 180 131 106 110 101 80 107 111 116 107 55 35 50 33 35 31
44 58 53 74 52 72 84 55 49 45 63 87 111 84 87 72 66 46 30 47
72 80 96 126 91 94 107 106 96 75 73 91 117 81 82 64 56 65 91 85
60 81 94 74 77 72 58 85 78 80 76 89 73 87 51 72 50 52 50 89
60 78 67 78 74 94 53
DND-R09A 41
131 199 103 268 351 323 203 221 130 149 208 248 251 263 391 463 289 361 278 298
242 258 209 257 321 376 431 449 368 327 397 288 309 529 297 405 330 365 451 352
486
DND-R09B 41
154 210 98 259 371 323 201 222 137 157 213 238 261 253 390 439 283 371 278 298
249 267 214 254 315 380 434 446 370 329 398 290 305 537 299 405 327 361 446 359
497
DND-R10A 60
347 288 328 333 424 362 341 370 139 105 229 244 275 261 232 189 220 250 329 230
321 276 246 124 111 121 123 150 161 155 239 241 132 139 150 207 276 166 112 218
143 128 136 154 181 217 168 261 191 255 224 255 144 142 176 126 81 132 158 159
DND-R10B 60
348 292 325 330 430 353 341 369 135 122 218 242 285 260 233 186 221 252 328 231
319 276 252 122 108 122 122 149 160 156 241 246 131 136 154 204 273 170 120 207
157 128 131 149 172 206 155 262 186 259 219 260 139 147 180 120 88 120 168 160
DND-R11A 81
168 198 211 245 162 122 99 124 149 158 131 125 165 115 118 94 106 51 59 43
34 49 47 78 66 57 73 59 49 38 47 52 46 39 49 30 63 73 78 62
59 65 63 64 69 87 100 84 65 58 36 145 168 235 210 192 130 138 147 167
132 170 145 152 132 183 186 167 152 186 128 119 110 129 139 97 118 104 112 115
100
DND-R11B 81
224 185 203 246 162 115 105 125 145 154 131 126 169 117 106 101 116 59 57 39
44 47 41 83 66 52 76 60 44 53 44 43 47 58 35 26 57 73 74 66
58 63 70 63 67 87 115 69 61 65 45 113 128 200 188 171 138 142 179 198
164 191 170 159 131 170 167 150 144 161 115 120 109 120 134 105 110 131 118 112
114
DND-R12A 45
149 231 243 215 234 375 346 298 122 233 242 189 150 153 183 223 235 240 206 246
255 171 106 166 190 247 207 203 170 270 242 381 371 507 386 284 300 218 89 77
76 79 89 109 106
DND-R12B 45
143 226 252 222 238 374 345 298 122 231 243 195 148 153 178 225 238 252 200 251

257 161 102 177 196 250 202 205 164 271 242 373 383 504 395 293 289 221 88 75
76 75 96 110 102
DND-R13A 45
104 140 124 140 154 123 197 152 137 229 282 142 105 72 113 126 133 203 195 148
119 119 132 147 190 141 112 123 135 181 122 128 105 161 160 147 121 128 205 166
138 139 124 73 73
DND-R13B 45
105 139 124 139 154 128 196 156 126 227 282 147 106 70 114 126 131 214 199 142
112 120 137 147 191 142 114 121 132 186 115 125 111 160 162 138 122 138 193 162
141 152 118 77 66
DND-R14A 186
132 164 151 178 276 189 171 154 138 148 148 173 188 200 249 267 302 265 190 268
229 259 176 162 215 257 303 197 266 166 158 71 111 166 137 207 173 136 117 127
191 153 124 106 103 94 77 138 137 94 115 87 64 65 77 98 150 171 175 191
114 85 84 88 78 64 111 159 145 97 111 91 142 134 115 181 170 121 123 82
121 129 91 86 88 67 76 49 60 72 60 87 60 65 87 66 67 73 79 66
71 49 40 48 42 61 63 45 47 46 32 28 27 33 35 44 44 38 60 33
43 69 43 50 36 53 60 65 77 72 87 90 88 91 120 109 133 102 105 195
167 126 191 219 188 195 213 153 94 105 134 167 138 136 109 147 210 191 162 130
85 150 105 86 104 130 192 206 145 121 134 131 94 88 104 125 161 146 179 130
124 112 112 110 107 117
DND-R14B 186
149 165 147 141 262 197 177 152 138 149 146 174 175 193 243 268 305 247 185 271
226 246 175 162 217 242 303 194 263 166 159 74 111 151 148 206 169 136 128 121
174 142 132 105 102 95 85 130 138 91 119 85 60 69 73 99 140 169 176 193
115 91 79 88 74 63 117 161 132 97 109 94 138 132 116 173 174 126 122 90
113 124 94 91 86 69 74 44 67 72 60 85 64 67 81 75 63 71 84 67
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169 127 191 220 198 194 207 148 92 112 115 168 138 138 104 145 209 184 172 133
91 143 108 87 101 134 190 205 150 120 132 128 96 91 98 130 161 145 179 131
122 103 108 119 100 113
DND-R16A 88
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117 168 174 297 239 306 287 286 275 262 237 266 264 151 168 221 252 161 137 96
58 75 54 44 55 60 60 94 45 72 66 59 88 82 72 74 120 115 122 117
132 105 144 128 93 109 123 129 174 157 231 164 232 160 187 182 169 184 205 185
217 274 175 146 118 98 83 101
DND-R16B 88
79 80 58 85 41 30 39 33 35 62 96 69 100 75 81 90 99 53 97 142
108 172 177 291 236 311 291 273 277 257 238 262 267 158 156 216 239 145 127 93
64 77 45 40 62 61 63 92 44 72 56 62 93 81 72 73 120 116 115 121
131 105 141 123 97 114 126 133 181 163 232 160 228 163 183 175 172 181 210 191
216 272 181 147 119 98 88 104
DND-R19A 58
225 473 172 142 243 271 149 142 152 193 188 173 331 422 447 272 207 189 242 518
591 362 387 310 124 156 196 239 332 360 361 362 301 306 121 223 384 561 426 453
328 365 277 260 226 225 305 233 387 285 425 215 190 294 264 260 321 361
DND-R19B 58
224 481 161 137 240 272 151 137 168 228 171 175 327 424 440 275 188 202 257 510
587 359 387 312 126 159 201 230 340 364 360 361 300 308 119 231 374 548 421 462
332 370 269 270 221 216 301 247 371 280 417 217 187 295 258 264 325 355
DND-R20A 51

220 217 271 257 392 273 194 202 198 168 175 196 262 192 255 249 261 121 126 145
124 145 126 145 154 168 81 86 143 207 263 155 82 111 70 98 116 181 184 262
200 293 211 299 274 268 103 136 156 120 102
DND-R20B 51
213 224 270 253 399 268 228 230 192 165 173 185 251 185 255 229 247 121 131 158
124 141 128 146 152 156 80 83 149 187 258 154 75 119 71 93 116 157 189 263
199 291 205 308 278 275 106 131 133 126 93
DND-R21A 63
235 250 237 246 200 204 315 247 278 234 270 238 264 332 218 154 139 198 156 102
73 72 82 112 82 174 301 327 307 308 269 265 187 212 184 161 217 269 229 140
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164 205 151
DND-R21B 63
216 246 223 259 206 199 306 250 270 230 266 229 262 335 207 157 134 204 155 98
78 71 83 111 83 172 301 328 306 314 259 268 191 206 182 166 227 279 227 142
98 171 166 201 159 194 144 156 185 149 213 187 139 180 119 189 185 225 136 167
167 203 149
DND-R22A 46
279 323 247 240 280 405 442 439 234 213 206 198 163 94 162 176 206 159 208 172
132 118 138 143 83 197 160 186 167 185 168 180 197 182 266 204 244 175 223 223
201 276 197 67 83 56
DND-R22B 46
250 321 251 236 286 401 451 464 237 214 205 201 162 98 165 165 206 159 209 170
134 110 148 148 86 202 162 184 174 190 163 178 197 184 265 215 234 171 230 216
202 276 190 72 60 59
DND-R23A 144
145 156 133 153 139 100 51 41 46 72 122 164 65 48 50 49 23 49 81 58
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65 104 149 168 129 149 254 216 256 154 170 135 70 114 128 130 125 137 116 84
84 93 103 92 90 71 68 58 54 88 133 87 97 72 58 67 38 48 80 103
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70 46 63 59 43 51 65 69 50 57 65 35 69 85 81 112 107 88 124 113
90 96 143 83 41 81 60 73 83 72 50 71 56 59 67 42 23 26 29 14
25 28 22 29
DND-R23B 144
152 154 146 153 141 101 50 42 46 73 120 165 64 47 52 48 25 49 83 53
58 54 53 68 88 69 122 86 100 86 57 65 49 67 75 107 92 136 157 139
75 108 157 167 134 147 260 221 263 153 170 135 65 115 127 132 133 137 111 87
74 94 103 103 87 74 64 58 57 81 124 91 93 67 59 68 36 54 73 111
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73 42 56 57 46 53 65 61 45 65 59 41 66 87 77 121 111 88 120 109
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31 23 22 16
DND-R24A 66
63 66 107 140 154 120 127 114 126 97 83 102 135 146 111 159 161 178 181 116
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166 170 110 89 146 123
DND-R24B 66
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132 141 98 131 123 198 151 148 163 138 175 167 185 174 414 247 182 200 150 161
155 173 108 90 121 130

DND-R25A 54
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223 424 243 183 160 203 237 176 158 217 185 306 224 307
DND-R25B 54
 46 84 56 53 58 33 39 39 57 40 63 59 39 42 53 82 49 48 60 79
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223 421 249 209 156 227 241 158 157 206 190 313 231 326
DND-R27A 104
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 97 83 86 90 73 78 95 69 91 124 76 96 85 96 77 84 80 109 104 110
 98 113 109 105 96 56 77 105 101 69 114 115 96 111 87 97 74 67 71 104
107 96 74 89 118 133 130 104 75 126 88 84 96 110 122 169 109 110 113 138
 82 83 90 112 141 136 153 121 108 100 84 100 86 137 134 156 136 103 136 110
118 132 162 166
DND-R27B 104
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102 94 87 87 83 80 96 73 84 128 73 96 86 111 77 88 71 108 101 104
103 118 104 104 97 61 80 105 99 76 115 128 94 96 89 96 67 66 65 104
106 96 76 87 114 130 123 111 81 132 80 86 98 111 126 165 109 110 119 126
 91 82 89 118 139 138 146 124 103 104 81 102 88 135 132 156 132 102 142 99
124 133 160 162
DND-R28A 97
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134 116 112 93 150 133 141 155 111 70 97 74 71 82 74 118 145 94 88 93
 93 95 71 90 120 143 126 154 120 91 116 100 108 91 193 144 181 141 165 177
134 144 122 133 154 114 132 95 97 153 153 82 80 102 86 64 79
DND-R28B 97
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130 115 157 141 164 142 92 119 172 143 127 177 155 149 140 138 141 130 107 83
108 125 116 85 145 132 147 149 109 74 97 70 73 87 90 142 152 99 89 91
 99 92 72 87 124 139 135 146 117 96 113 104 104 92 193 148 185 134 169 176
126 150 126 134 151 113 131 102 104 135 165 83 78 102 87 60 78
DND-R29A 97
291 196 218 154 193 203 255 67 70 127 118 188 118 136 89 87 86 130 127 103
108 136 143 88 220 192 130 261 197 291 384 336 278 356 332 217 308 287 196 258
285 146 89 86 81 133 176 143 116 100 165 154 129 117 108 86 72 82 109 88
104 112 70 58 62 67 42 71 70 77 94 71 69 98 72 65 43 48 47 78
 41 54 42 73 82 92 90 80 124 97 84 94 80 124 101 113 102
DND-R29B 97
285 202 220 155 189 197 249 69 61 130 116 191 109 136 87 82 83 121 126 105
109 137 144 86 226 189 128 259 198 289 384 320 260 351 333 211 317 280 192 267
298 146 92 86 79 135 169 148 114 104 163 151 132 115 107 82 72 84 107 88
108 110 69 55 62 71 38 68 75 71 92 77 75 90 64 64 53 43 50 71
 44 60 51 66 75 100 81 93 110 91 86 97 89 104 95 111 103
DND-R30A 101
384 355 270 327 284 305 273 321 85 74 110 124 162 144 198 238 260 275 379 191
178 142 156 149 126 195 134 116 106 89 116 124 107 119 126 130 107 199 147 165
193 131 150 178 175 129 144 160 140 149 141 182 221 212 170 176 194 160 156 171
157 180 281 124 64 67 81 62 95 106 108 160 137 168 169 146 136 117 133 134
183 149 138 141 111 177 234 293 294 299 304 212 239 213 115 106 220 174 151 137
148

DND-R30B 101
382 358 271 330 275 308 277 311 88 77 103 134 171 133 201 235 257 268 382 189
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186 136 151 185 172 128 147 174 147 142 150 182 215 211 171 176 203 150 154 155
153 175 274 116 67 69 77 66 90 113 102 161 137 172 172 143 142 105 140 146
178 146 143 130 125 177 241 306 302 304 314 217 236 223 101 102 217 167 147 145
142
DND-R31A 86
202 263 154 179 218 149 141 221 206 121 104 96 114 311 312 266 179 92 244 153
65 239 287 236 273 189 185 213 131 136 262 124 182 206 143 80 44 73 104 212
108 205 161 145 45 59 75 85 56 78 114 140 158 89 90 99 47 86 126 148
97 112 61 55 54 92 168 108 80 71 51 66 74 133 182 114 154 86 71 75
32 61 94 113 153 192
DND-R31B 86
204 267 163 178 221 142 146 222 199 123 109 95 115 301 300 270 180 89 247 153
66 239 280 241 274 186 189 212 133 134 262 121 181 206 147 79 42 72 104 220
100 214 161 162 46 58 76 85 56 77 115 136 161 89 87 95 51 87 125 149
98 121 62 50 55 92 173 100 80 64 58 65 77 131 182 111 153 81 79 68
33 60 92 114 150 206
DND-R32A 86
252 300 262 133 234 133 111 191 130 117 206 238 177 87 52 47 97 194 217 147
87 163 111 78 180 224 200 223 157 121 148 99 71 104 71 107 58 57 43 37
54 107 186 182 375 243 160 88 111 115 124 76 124 143 115 145 101 178 144 67
110 116 109 127 114 71 66 59 91 82 160 86 70 60 60 49 67 86 154 78
61 42 47 56 36 36
DND-R32B 86
254 299 263 133 226 132 111 172 130 116 203 237 177 84 54 51 96 191 215 124
79 163 116 76 182 228 198 213 164 109 143 94 71 99 65 106 57 57 41 36
52 106 180 187 387 243 162 84 111 119 120 80 130 144 127 149 97 181 148 66
109 113 108 127 115 70 67 53 94 70 164 86 72 60 58 54 62 93 153 73
61 44 47 52 35 34
DND-R33A 166
116 147 165 226 111 145 148 56 105 134 174 119 180 79 62 79 169 240 174 125
110 70 75 63 141 197 104 150 64 68 57 20 47 75 81 102 169 60 66 97
38 49 41 40 56 52 40 33 49 27 35 35 51 59 51 47 19 37 46 37
50 50 39 31 42 39 33 37 71 68 90 59 37 51 51 42 40 74 55 36
91 62 41 45 60 49 60 39 50 73 35 36 46 45 37 41 33 32 36 31
31 33 48 48 36 39 32 32 40 29 32 28 36 26 32 23 19 28 31 25
23 21 24 35 33 28 26 27 26 42 41 43 38 30 29 31 30 28 25 26
20 23 33 29 32 36 26 40 32 28 26 23 30 35 24 24 21 23 23 23
27 53 84 59 29 32
DND-R33B 166
98 148 139 228 116 147 151 51 118 135 168 122 174 92 66 76 166 250 178 129
115 66 71 52 139 199 103 138 70 67 57 19 45 85 75 105 170 61 60 104
45 53 39 39 62 48 42 29 40 33 34 30 43 72 62 47 17 35 44 32
36 55 46 46 45 37 39 39 74 54 86 62 37 49 51 43 40 77 54 38
92 58 49 47 62 45 61 35 58 73 34 35 47 46 39 41 32 31 39 27
35 33 50 45 36 40 32 36 34 28 33 29 35 28 30 24 17 31 29 27
23 23 24 33 33 28 24 26 29 41 49 42 36 32 29 31 24 31 25 24
27 21 33 28 28 38 37 28 35 27 29 24 33 27 22 24 24 28 24 21
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DND-R34A 147
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98 94 78 109 155 105 101 119 85 65 54 61 104 117 109 110 70 85 81 79
75 70 105 102 134 109 94 87 58 82 88 81 91 72 93 56 82 102 75 83
103 64 61 55 54 57 71 51 51 77 76 76 91 71 86 85 74 79 35 67
81 77 82 80 48 82 60 66 76 88 89 121 92 99 101 76 83 102 98 77
86 59 56 56 61 60 112 61 60 65 52 69 76 75 64 71 61 63 92 76
90 89 66 74 54 58 58 69 72 76 51 44 101 82 85 55 40 71 60 42
54 54 62 73 54 48 53
DND-R34B 147
132 93 91 64 75 59 73 76 87 84 106 118 120 131 149 181 168 138 168 159
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75 71 105 99 138 109 95 79 64 76 95 73 97 68 96 51 89 97 78 84
106 65 55 62 52 61 64 55 44 78 74 78 89 75 85 78 81 75 37 68
79 79 72 88 43 85 59 64 83 78 93 114 86 99 104 71 92 111 108 83
86 61 57 57 61 67 102 73 58 63 55 68 76 74 63 72 61 64 93 72
92 84 71 71 59 53 61 67 77 78 42 51 98 84 81 57 44 71 56 44
53 56 60 72 55 48 55
DND-R35A 97
136 124 140 114 120 128 92 118 110 84 93 89 70 64 47 54 77 47 49 51
45 55 56 63 48 43 77 62 61 67 49 65 58 53 62 57 58 50 68 81
82 80 63 79 84 85 74 68 75 74 55 65 68 60 79 81 89 61 64 74
56 96 108 98 77 105 101 79 100 89 72 88 82 91 77 77 101 74 87 90
108 94 85 77 65 52 74 86 65 41 51 43 41 42 41 36 46
DND-R35B 97
136 107 147 119 126 118 102 122 113 85 92 93 67 73 47 52 76 53 51 45
49 48 57 64 48 47 70 56 67 57 48 58 61 52 60 60 53 55 61 88
95 70 62 80 96 74 83 63 72 69 60 70 67 64 97 68 92 68 70 67
73 97 83 109 98 78 87 89 78 69 60 100 88 92 69 80 96 78 88 90
95 100 79 79 64 51 81 80 73 39 48 39 45 41 38 47 38
DND-R36A 77
164 154 151 115 107 80 82 96 132 97 94 105 89 66 40 80 94 100 111 171
96 85 103 93 118 91 119 135 126 104 72 69 120 79 100 88 91 67 125 77
90 99 92 94 81 75 62 76 91 77 83 91 133 129 102 93 95 103 125 97
123 105 55 123 96 111 110 86 48 108 64 81 70 80 57 70 145
DND-R36B 77
170 162 145 127 97 87 83 104 135 94 100 100 89 60 48 79 86 99 119 162
92 87 102 98 114 88 115 134 116 100 68 77 111 87 100 85 90 69 122 80
87 94 80 89 84 78 65 89 83 68 75 86 126 128 102 89 98 101 121 99
124 113 56 127 101 110 108 89 47 98 72 79 74 77 50 70 149
DND-R37A 88
178 212 91 103 187 170 186 145 199 127 102 162 183 173 160 149 110 104 149 127
132 121 84 92 94 76 95 115 113 133 107 87 96 75 48 100 108 150 146 137
98 64 51 68 66 54 62 103 119 86 63 87 62 47 60 85 85 71 86 103
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95 94 80 104 62 83 78 78
DND-R37B 88
183 221 81 107 184 181 186 138 200 127 103 157 184 171 167 148 109 104 144 134
133 112 84 92 94 77 97 109 118 135 104 86 99 75 50 98 103 147 149 134
99 67 47 68 56 61 63 102 122 89 71 86 58 59 58 78 93 65 83 96
89 69 51 102 66 63 64 69 67 86 89 81 58 65 104 85 93 79 84 92
90 95 91 107 71 74 78 87
DND-R38A 97
201 213 181 149 236 233 240 245 268 247 176 139 105 115 112 143 239 182 184 234
207 151 167 117 152 181 171 169 148 147 98 156 183 189 136 114 131 141 136 114

113 94 71 94 106 139 129 108 106 96 103 111 156 99 98 79 81 71 75 110
138 117 93 70 60 74 42 68 78 90 113 133 104 69 61 66 58 68 71 89
104 99 72 82 69 64 79 77 93 86 103 102 74 87 65 72 75
DND-R38B 97
206 214 184 145 243 230 241 244 261 252 181 138 102 109 114 142 245 188 183 224
206 145 171 112 161 183 171 171 147 144 100 153 181 186 133 108 132 144 133 115
112 99 72 94 105 146 130 106 105 97 100 112 154 104 96 82 75 75 80 108
143 114 94 71 62 70 42 69 74 92 115 135 95 70 63 64 60 65 69 89
108 98 71 83 65 68 80 79 91 78 115 94 81 80 61 84 64
DND-R39A 70
321 286 342 309 321 285 225 214 263 250 249 281 335 100 143 252 228 275 173 200
198 237 274 314 268 246 240 190 198 154 201 188 136 131 135 181 189 169 149 157
189 125 219 155 181 200 154 161 118 153 130 151 184 149 143 97 152 161 164 156
162 154 109 92 127 130 190 259 189 159
DND-R39B 70
303 284 343 317 315 280 213 190 280 245 243 274 322 112 158 245 227 266 185 196
197 237 275 313 274 225 262 194 193 155 206 200 143 148 139 190 175 163 146 143
198 125 212 165 184 199 148 166 123 151 125 154 181 141 128 97 164 162 175 155
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DND-R40A 90
307 255 328 225 303 215 401 154 211 310 284 339 252 234 249 210 231 247 230 178
157 171 155 138 180 176 168 197 206 245 255 222 226 274 304 134 264 266 245 270
227 256 202 181 180 198 219 174 141 118 199 195 156 140 137 147 87 81 113 125
172 226 179 143 168 135 91 117 149 157 153 123 131 147 88 84 52 73 78 105
74 93 50 83 99 90 138 127 139 124
DND-R40B 90
321 255 321 228 297 221 393 158 206 313 275 332 243 232 248 202 233 251 224 177
159 169 160 135 179 175 165 202 204 250 255 222 226 281 313 117 263 268 246 269
227 260 195 182 180 201 205 177 137 125 190 197 155 146 130 151 88 78 111 128
176 220 170 145 166 134 88 120 149 157 155 121 128 145 95 80 58 69 79 107
76 86 50 88 98 90 137 126 143 130
DND-R41A 64
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48 50 69 71 67 94 70 79 97 76 95 70 90 78 78 72 98 89 87 68
85 109 97 92 64 79 126 102 94 146 125 157 145 155 158 122 127 115 144 161
149 123 145 167
DND-R41B 64
167 149 128 190 326 320 174 188 122 122 172 145 112 112 103 61 59 47 53 52
54 48 71 71 69 94 73 79 96 76 95 68 90 79 77 69 97 94 88 67
110 104 92 102 66 86 130 102 95 143 134 165 159 155 169 123 140 114 144 162
155 116 149 166
DND-R42A 65
25 20 10 23 28 23 21 30 33 35 35 43 28 28 70 60 50 45 26 20
15 20 22 18 13 10 20 10 15 11 22 10 14 5 5 9 11 10 15 20
28 35 30 27 20 22 30 40 30 35 20 34 27 33 33 20 22 28 50 45
60 35 28 30 40
DND-R42B 65
25 20 15 25 28 25 20 30 35 34 35 40 30 25 65 55 50 45 25 20
13 18 25 10 13 10 28 8 14 14 23 13 10 5 5 8 15 10 18 18
25 32 25 24 18 20 30 42 30 35 25 40 30 35 32 20 26 28 55 50
60 35 25 20 50
DND-R43A 55
4 5 6 5 5 7 7 8 10 7 10 10 11 12 17 25 20 23 18 17

10 6 13 15 13 12 17 11 10 12 15 12 8 8 9 10 9 7 8 7
7 7 6 12 8 12 11 13 11 12 15 14 15 16 15
DND-R43B 55
4 6 5 5 6 8 8 7 9 7 10 10 10 13 17 23 20 25 15 15
10 5 12 15 12 11 18 12 13 10 13 11 10 10 10 11 10 8 10 6
8 8 6 12 10 12 11 13 13 14 13 15 15 16 14
DND-R44A 70
30 22 18 20 22 30 30 17 14 20 29 15 29 24 27 20 24 15 27 15
10 18 17 10 15 15 17 18 18 14 21 23 34 25 20 18 21 17 16 15
25 33 25 25 15 19 25 15 25 20 20 30 41 25 30 20 23 23 10 23
20 28 15 16 10 10 11 10 11 15
DND-R44B 70
30 24 19 20 23 30 30 16 17 25 27 16 27 23 27 19 23 15 18 18
17 17 18 11 15 13 17 10 18 16 21 20 35 30 22 20 20 20 11 23
22 33 23 25 20 25 23 16 24 20 23 31 37 24 30 20 23 24 12 27
19 28 13 20 10 9 11 8 12 10
DND-R45A 47 (inner section)
35 38 30 25 22 30 30 35 40 32 30 31 37 37 25 19 45 30 27 28
35 35 37 7 11 15 15 15 20 14 12 11 8 10 9 10 12 7 12 10
18 16 11 16 11 10 10
DND-R45B 47
35 38 35 28 20 30 30 36 42 35 30 30 36 41 27 19 50 33 26 28
35 37 40 9 10 15 16 15 17 15 11 12 10 9 8 10 11 9 11 10
20 18 8 18 13 10 8
DND-T45A 69 (outer section)
8 6 8 10 6 5 8 10 12 13 10 13 11 14 18 21 41 27 28 20
20 15 8 20 20 20 20 28 15 17 18 15 18 16 20 30 35 25 30 20
13 23 14 11 20 13 24 20 15 15 18 16 17 11 17 22 9 10 20 12
14 18 15 13 8 9 9 9 7
DND-T45B 69
10 7 10 10 6 5 8 8 12 13 10 12 13 14 17 20 40 28 27 20
20 15 9 20 21 21 19 28 18 17 15 20 20 15 18 25 30 30 25 23
15 25 15 12 19 14 22 20 15 16 18 16 17 12 18 21 9 10 18 14
15 19 16 13 8 8 9 9 8
DND-R46A 51
301 306 214 197 213 190 209 232 197 194 309 235 239 204 212 168 140 150 155 194
222 172 181 210 155 170 176 155 154 174 177 218 144 165 182 181 178 118 174 178
246 183 194 146 184 146 133 136 169 113 153
DND-R46B 51
297 296 229 176 214 181 213 233 212 202 297 224 233 206 214 176 146 146 153 198
229 165 175 213 155 164 179 153 151 168 180 222 152 171 181 181 181 112 170 188
254 176 185 150 185 131 141 133 167 116 150
DND-R47A 102
129 147 155 186 125 102 138 102 69 77 101 173 194 134 138 119 153 105 55 112
152 141 157 171 164 138 128 119 113 104 99 113 131 120 98 111 104 144 150 145
97 95 122 112 135 86 108 112 83 91 90 107 96 87 53 82 64 77 61 85
81 72 94 88 76 94 73 145 88 95 80 88 73 83 104 132 105 91 96 82
89 86 46 70 67 73 90 84 77 78 84 80 65 68 58 91 85 76 85 75
83 108
DND-R47B 102
128 139 160 189 126 125 159 107 75 72 100 170 205 118 142 123 161 95 64 100
150 143 157 176 163 140 123 122 115 99 104 113 121 127 119 119 113 149 144 140
102 100 130 119 126 90 113 112 89 98 92 111 102 94 63 79 76 79 62 87

85 84 82 90 73 95 73 117 98 91 83 86 72 77 111 130 94 95 88 87
91 87 51 67 71 69 77 81 85 72 83 77 68 67 54 96 81 77 90 70
85 105
DND-R48A 92
116 157 134 103 71 145 142 89 111 130 134 180 179 104 124 92 110 112 125 88
134 112 122 106 119 98 89 92 131 159 132 141 136 111 110 100 147 239 156 130
149 127 124 73 104 109 155 138 191 155 182 157 128 118 121 121 136 186 143 157
136 85 115 100 101 127 128 210 195 108 78 71 47 78 90 59 87 65 61 50
46 43 62 123 103 103 71 76 60 75 70 60
DND-R48B 92
118 159 132 104 78 136 138 93 112 117 129 176 171 107 115 105 100 104 128 90
213 131 124 87 126 90 93 89 135 157 135 146 135 101 112 96 144 249 148 128
152 125 123 74 100 101 157 144 197 139 176 156 135 111 134 117 137 194 149 155
139 74 116 97 104 132 130 207 194 104 77 69 61 67 90 60 83 68 57 52
56 45 64 118 99 120 79 69 60 73 63 57
DND-R49A 61
516 439 311 284 240 117 151 181 204 204 215 119 154 221 167 131 144 110 147 229
188 164 174 203 137 108 109 165 248 191 136 172 186 145 158 268 123 142 165 216
144 155 100 86 140 137 124 186 149 222 204 185 154 89 69 80 53 155 178 219
160
DND-R49B 61
514 439 315 270 239 116 151 184 199 212 225 129 171 228 161 111 138 117 178 218
193 149 157 202 143 109 113 164 247 185 121 180 186 143 154 271 124 145 157 213
168 154 99 78 148 134 120 193 165 221 198 180 154 98 58 70 63 162 161 225
162
DND-R50A 152
588 556 443 459 465 285 390 348 276 264 211 221 174 192 224 234 280 193 428 227
191 304 306 192 126 165 156 200 231 200 238 173 238 155 106 80 64 79 112 147
139 142 177 143 130 187 182 213 135 179 261 209 147 161 169 136 121 188 255 216
219 257 189 136 133 233 268 250 209 300 252 341 253 318 386 191 296 228 178 107
39 39 36 49 81 181 120 146 132 95 78 81 64 73 79 44 48 67 23 37
30 61 69 88 73 76 142 71 91 80 92 73 99 84 93 81 46 35 37 48
84 80 101 152 149 119 129 77 72 118 136 125 120 133 97 85 68 128 111 137
111 122 113 119 116 110 125 137 101 153 116 278
DND-R50B 152
609 542 435 451 477 271 402 282 289 252 222 253 199 192 217 250 253 200 409 256
214 299 280 192 135 158 156 198 225 199 245 176 245 169 98 90 85 102 137 157
138 152 178 144 129 189 185 207 139 180 253 210 147 153 165 123 131 192 251 210
224 248 179 149 132 218 286 263 202 285 239 344 241 329 374 219 284 217 177 101
39 36 47 54 95 215 121 130 124 97 80 63 54 84 70 56 39 48 29 34
39 56 72 90 77 79 119 75 81 76 86 87 85 74 100 72 55 37 36 57
103 71 105 163 165 142 122 78 71 123 131 136 123 148 97 79 51 133 124 151
99 117 98 125 116 125 123 134 106 156 148 249
DND-R51A 75
90 121 166 156 159 215 172 195 247 243 267 216 150 246 336 249 195 198 182 265
211 306 256 227 188 184 117 160 225 216 254 294 310 248 383 313 186 208 168 204
238 187 177 176 230 145 136 97 127 208 144 179 181 168 208 123 183 111 148 142
134 113 118 71 111 124 109 156 153 134 189 151 176 183 165
DND-R51B 75
102 106 168 149 168 220 170 193 245 217 268 219 153 235 337 240 220 203 187 260
211 296 259 219 196 183 121 154 224 218 257 295 308 244 383 311 195 204 174 201
203 183 215 217 190 156 152 93 132 206 144 182 181 164 208 121 187 103 151 136
138 111 120 77 98 116 102 154 129 123 162 143 170 213 146

DND-R52A 71
589 466 437 613 455 347 181 44 39 19 39 52 48 81 83 93 159 175 159 93
380 235 208 211 250 215 122 102 126 219 256 219 332 135 171 123 92 93 74 93
107 147 220 361 356 273 151 382 262 355 195 190 299 274 148 133 115 137 91 156
115 123 144 162 138 116 113 160 282 166 101
DND-R52B 71
608 459 424 603 512 346 162 40 33 27 44 62 52 90 77 96 159 178 159 90
452 234 186 206 246 215 118 107 123 222 258 226 328 179 180 154 104 101 73 74
113 152 223 356 352 265 147 328 258 393 182 180 286 282 154 124 119 137 94 149
125 116 145 161 140 117 110 163 276 179 91
DND-R53A 133
169 103 73 63 61 55 82 75 181 272 294 214 128 172 155 151 49 61 38 46
56 103 50 55 33 32 37 31 34 30 38 43 64 80 118 76 47 51 61 81
66 72 147 195 131 112 128 135 184 160 201 281 314 319 164 138 185 233 218 221
159 130 132 179 106 108 145 98 145 134 114 146 177 119 134 192 109 97 120 118
122 172 190 136 123 69 68 68 75 53 115 143 86 132 104 100 132 128 185 172
174 144 97 80 130 159 205 133 225 194 285 216 119 80 161 184 199 262 268 275
209 190 158 161 263 233 278 292 237 134 197 303 191
DND-R53B 133
151 104 67 65 57 57 88 80 197 278 313 304 130 165 158 146 70 49 54 45
73 104 52 43 46 30 35 40 44 21 30 41 67 74 115 74 47 48 69 75
64 78 144 196 133 116 128 131 191 153 199 288 312 318 157 136 187 236 213 229
144 125 135 179 114 100 145 100 137 132 108 151 172 142 120 199 111 94 127 120
124 167 191 134 118 66 74 76 66 64 107 133 85 133 103 99 125 122 175 182
180 136 98 82 144 179 216 129 224 201 293 210 115 81 158 184 208 268 269 278
214 176 162 169 247 244 271 295 238 119 194 277 177
DND-R54A 72
336 505 431 352 201 332 377 374 365 238 300 229 215 177 348 290 284 258 173 273
199 172 157 195 183 162 161 173 163 169 156 125 110 170 164 206 202 229 169 126
138 147 171 166 137 149 180 161 172 155 202 183 172 145 217 149 160 149 125 136
117 105 143 164 103 108 91 94 83 79 77 86
DND-R54B 72
311 504 386 349 205 337 375 374 373 231 290 255 195 176 335 276 296 232 175 256
201 174 172 195 182 165 148 172 170 162 156 126 106 167 166 208 196 227 164 111
121 140 181 161 123 158 187 152 159 155 197 197 188 160 219 160 155 153 116 123
115 104 144 156 114 122 83 92 75 93 73 85
DND-R55A 99
314 339 335 253 338 315 335 438 417 277 209 547 301 309 340 328 433 324 327 285
434 414 399 202 145 124 122 111 108 192 210 239 256 259 403 438 336 286 339 316
351 354 316 441 397 398 355 352 324 250 260 323 305 266 296 260 180 283 312 347
234 225 207 161 274 243 417 365 275 329 304 146 170 127 180 251 232 224 367 242
163 117 152 121 110 140 205 258 197 219 204 151 149 200 187 159 151 215 146
DND-R55B 99
307 343 324 250 311 298 351 476 382 262 198 555 305 300 342 332 422 332 338 288
407 434 377 212 161 148 132 135 119 196 235 240 253 279 392 448 311 299 352 364
356 359 337 424 424 390 372 369 304 270 255 323 322 260 295 265 182 316 359 374
209 236 214 177 246 280 400 369 298 286 275 126 157 98 155 233 243 225 374 252
165 126 111 140 150 139 251 350 217 214 192 147 164 199 197 178 139 218 187
DND-R56A 90
139 109 137 73 118 163 164 86 97 118 181 159 124 111 74 88 96 95 68 80
151 224 154 102 112 112 80 123 142 108 160 123 166 169 107 85 99 166 145 178
172 105 100 103 210 164 118 378 194 137 200 206 164 92 53 67 83 110 125 238
181 190 118 68 124 180 92 82 98 166 323 277 113 78 95 71 80 87 71 141

161 171 88 113 87 75 60 54 80 68
DND-R56B 90
139 117 108 74 99 149 146 115 94 129 173 175 118 97 68 86 99 74 73 74
 99 161 140 100 75 96 68 129 141 102 162 116 168 175 117 79 107 166 144 178
163 105 110 104 205 166 139 378 204 141 194 208 169 88 42 63 68 116 118 234
181 205 112 75 88 135 79 68 73 131 364 314 98 69 105 76 84 93 70 135
167 164 86 112 91 60 55 51 69 88

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

Tree-ring dating, or dendrochronology as it is known, is discussed in some detail in the Laboratory's Monograph, *An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building* (Laxton and Litton 1988) and *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1998). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The width of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure A1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of oak timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

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

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

1. **Inspecting the Building and Sampling the Timbers.** Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample in situ timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique

position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure A2 has about 120 rings; about 20 of which are sapwood rings – the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood rings.

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

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

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

All sampling by the Laboratory is undertaken according to current Health and Safety Standards. The Laboratory's dendrochronologists are insured.

Figure A1: A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976

Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

Figure A3: Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis

Figure A4: Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical

2. **Measuring Ring Widths.** Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure A2. The core is then mounted on a movable table below a microscope and the ring-widths measured individually from the innermost ring to the outermost. The widths are automatically recorded in a computer file as they are measured (see Fig A3).

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

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

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

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

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

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

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

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

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

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

6. **Master Chronological Sequences.** Ultimately, to date a sequence of ring widths, or a site sequence, we need a master sequence of dated ring widths with which to cross-match it, a Master Chronology. To construct such a sequence we have to start with a sequence of widths whose dates are known and this means beginning with a sequence from an oak tree whose date of felling is known. In Figure A6 such a sequence is SHE-T, which came from a tree in Sherwood Forest which was blown down in a recent gale. After this other sequences which cross-match with it are added and gradually the sequence is 'pushed back in time' as far as the age of samples will allow. This process is illustrated in Figure A6. We have a master chronological sequence of widths for Nottinghamshire and East Midlands oak for each year from AD 882 to 1981. It is described in great detail in Laxton and Litton (1988), but the components it contains are shown here in the form of a bar diagram. As can be seen, it is well replicated in that for each year in this period there are several sample sequences having widths for that year. The master is the average of these. This master can now be used to date oak from this area and from the surrounding areas where the climate is very similar to that in the East Midlands. The Laboratory has also constructed a master for Kent (Laxton and Litton 1989). The method the Laboratory uses to construct a master sequence, such as the East Midlands and Kent, is completely objective and uses the Litton-Zainodin grouping procedure (Laxton *et al* 1988). Other laboratories and individuals have constructed masters for other areas and have made them available. As well as these masters, local (dated) site chronologies can be used to date other buildings from nearby. The Laboratory has hundreds of these site sequences from many parts of England and Wales covering many short periods.

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

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

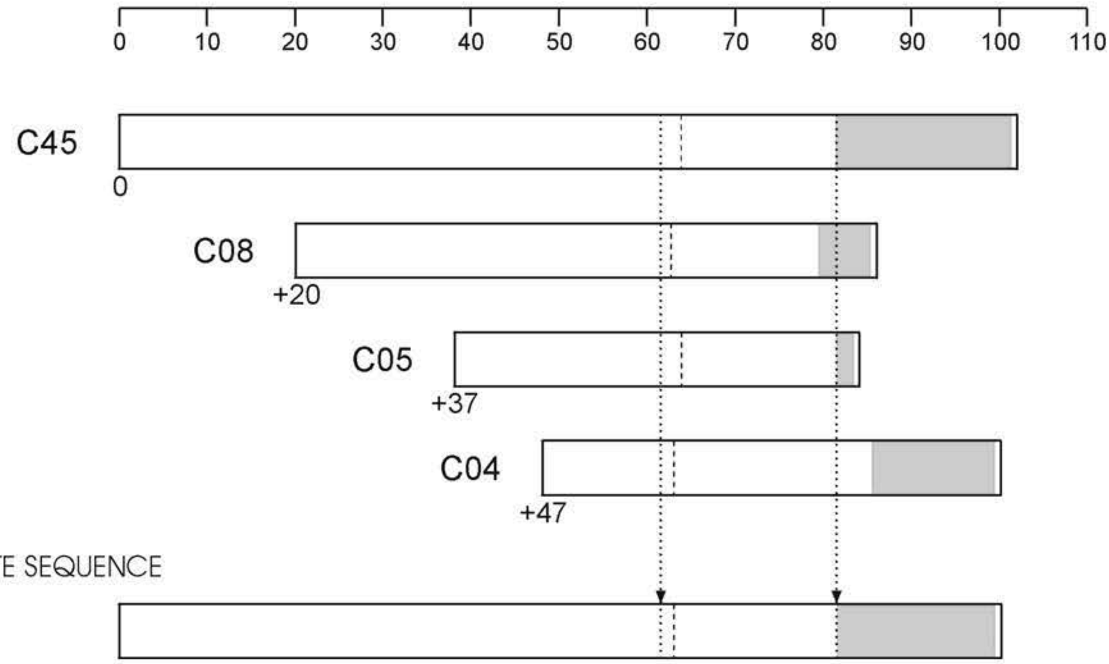


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

The bar diagram represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions (offsets) to each other at which they have maximum correlation as measured by the *t*-values. The *t*-value/offset matrix contains the maximum *t*-values below the diagonal and the offsets above it. Thus, the maximum *t*-value between C08 and C45 occurs at the offset of +20 rings and the *t*-value is then 5.6. The site sequence is composed of the average of the corresponding widths, as illustrated with one width.

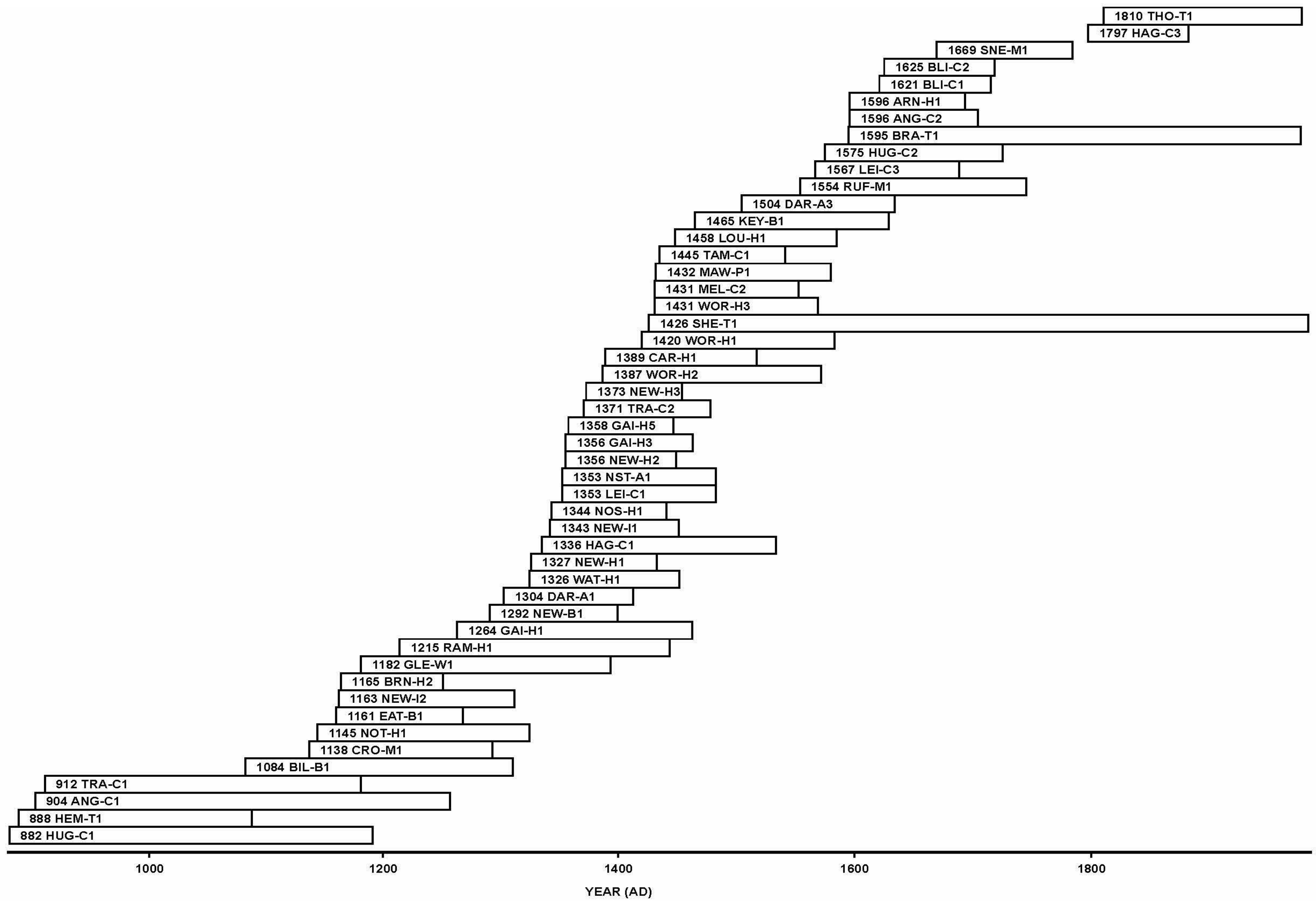
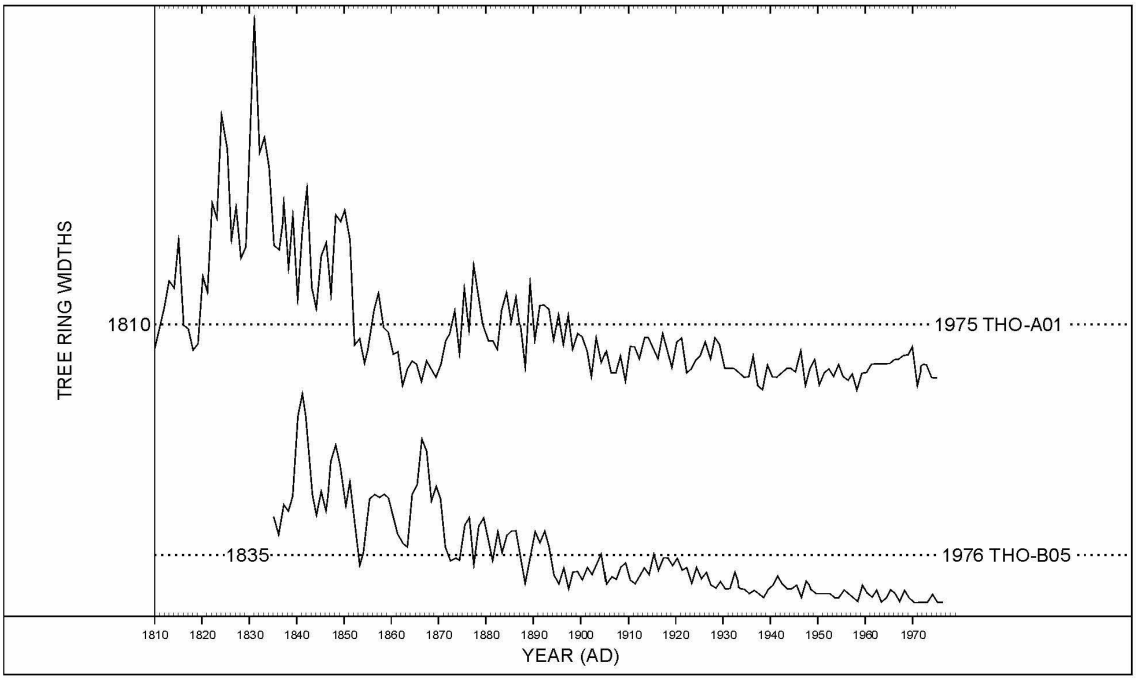


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

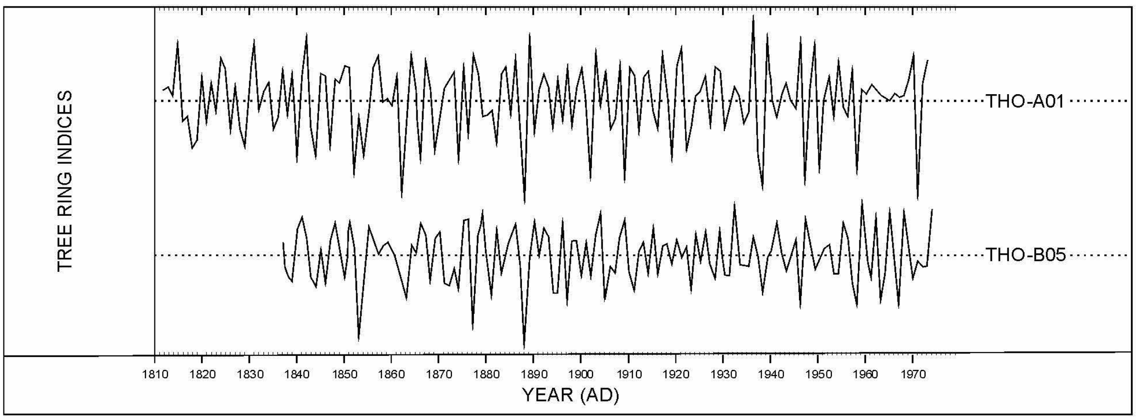


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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

The growth trends have been removed completely

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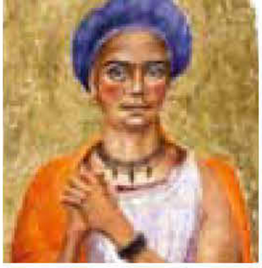

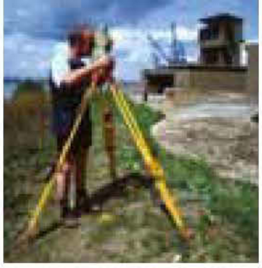

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