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

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Summary

Analysis of 45 samples from Carlisle Castle produced two site chronologies. The first, representing 33 timbers, has 479 rings spanning AD 968 - AD 1446. The second contains two samples, with 124 rings spanning AD 900 - AD 1023.

Interpretation of the sapwood indicates the earliest material, from the Keep, was probably not felled before *c* AD 1038; it is possibly reused from the Norman fortification of AD 1092. Other material here has a felling date in the range AD 1135 to AD 1160, possibly relating to construction by King David I of Scotland.

The majority of timbers in the roofs of de Ireby's Tower appear likely to have been felled in AD 1380, though possibly a few are felled later and may relate to alterations. The "prison room" ceiling timbers are also likely to have been felled in AD 1380 except for one felled in AD 1391, which could also relate to alterations.

The newel stair roof contains timber with a range of potential felling dates, and it is not possible to conclusively determine the construction date. The latest felling is probably not before AD 1461, and may represent repairs to damage incurred at about this time.

Keywords

Dendrochronology
Standing Building

Author's address

Nottingham Tree-Ring Dating Laboratory, Scool of Mathematics, University of Nottingham, University Park, Nottingham, NG7 2RD

Introduction

Carlisle Castle (NY 397 563; Fig 1), like so many other castles, is believed to have its origins as an earth and timber structure of the early Norman period. It is known that William II, otherwise known as "Rufus", came north to Carlisle in AD 1092 and, having constructed and garrisoned a new fortification here, drove out Dolfin of Northumbria. It was some thirty years later, in AD 1122, that Henry I, Rufus' brother, began converting the timber structure to stone, and substantially increased the size of the fortification. This work, including the construction of the Keep, the oldest presently surviving part of the Castle, was completed by King David I during a period of Scottish occupation of the northern counties which began in AD 1135. It was not until AD 1157, during the reign of Henry II, that Carlisle, and its Castle, was restored to the English.

From then to the middle of the twentieth century the Castle has undergone several major phases of building activity, witnessing in the interim several dramatic episodes in Anglo-Scottish boarder history. These periods of building include the addition in AD 1167-8 of a second encircling curtain with a gatehouse in the southern wall. It is this gatehouse, and its subsequent adaptations, that become known as de Ireby's Tower, after William de Ireby who stayed here in AD 1215. This new wall and its gatehouse apparently prevented the castles' capture by the Scottish King William I in AD 1174.

The Scottish were more successful in AD 1216 when, during the Baron's revolt against King John, Alexander II undermined the wall and gatehouse, and eventually captured the Keep. It is recorded that these buildings were still in a ruinous condition in AD 1256. Repairs and alterations appear to have been carried out in the late-thirteenth and early fourteenth centuries, as further Scottish attacks were made. Further late-fourteenth century building was undertaken. This work included the construction of a new and enlarged gatehouse in the south wall, in AD 1378 – 83, possibly incorporating part of the earlier, twelfth-century, one.

The tower was provided with platforms for cannons in the fifteenth century, perhaps as part of repair work caused during the siege of Carlisle in AD 1461 when the opposing sides both used artillery. Building work was also undertaken in the sixteenth and seventeenth centuries, though often on a smaller scale. Thus within the main curtain walls are several agglomerations of buildings, a general plan of the Castle being given in Figure 2.

Sampling

Sampling and analysis by tree-ring dating of timbers from several distinct parts of the Castle were commissioned by English Heritage. The purpose of this was to provide precise dating to support a mass of vague documentary evidence on the dating and development of the castle, which is considered a flagship property in the care of English Heritage (see McCarthy *et al* 1990). Sampling and analysis was requested from various groups of timbers in de Ireby's Tower, the Keep, and the west postern gate. Plans or illustrations of some of these areas are given in Figures 3 - 5.

From these areas a total of 45 samples was obtained, each sample being given the code CRL-D (for Carlisle, site "D") and numbered 01 - 45. Where possible the positions of the cores that were obtained were recorded at the time of sampling on drawings provided by English Heritage, these being reproduced here as Figures 6 - 8. The exception to this being a drawing to show the positions of the samples from the portcullis. Details of the samples are given in Table 1 and can be used in conjunction with the drawing to locate timbers sampled.

In this report the bays, ceiling, and roof timbers of the rooms in de Ireby's Tower have been numbered and described on a north to south, or east to west basis, as appropriate. The portcullis timbers have been similarly described. The boards of the ceiling of the Keep stairs have been numbered from bottom to top.

The Laboratory would like to take this opportunity of thanking the English Heritage staff of Carlisle Castle for their assistance during sampling. We would also like to thank the security man on duty that day, who was also most helpful.

de Ireby's Tower

The greater concentration of timbers considered in this programme of analysis is to be found in the area known as de Ireby's Tower (see Fig 3). This forms the bulk of the Castle's outer gatehouse, which, on the basis of stylistic evidence and documentary material in the form of building accounts, is believed to have been initially built AD 1167-8, and then reconstructed and substantially enlarged in the period AD 1378 – 83.

As can be seen from Figure 3, the solar is on a different alignment to the rest of the de Ireby's Tower, and is believed to be earlier, possibly being part of the former, twelfth-century, gatehouse.

de Ireby's Tower - "prison room" ceiling

The ceiling of what is now referred to as the "prison room", at first-floor level, comprises substantial close-laid baulks. Sampling of these timbers was requested to establish whether they date from a phase of felling earlier than the rest of de Ireby's Tower and to determine whether they are contemporary with the solar roof above. Eight of these ceiling timbers were cored providing samples CRL-D11 – D18.

de Ireby's Tower - solar roof

This roof consists of shallow pitched principal trusses with tiebeams, there being common rafters of similar size to the principal between each truss. The trusses and common rafters carry a ridge beam. Sampling of these timbers was requested to establish whether they date from a phase of felling earlier than the rest of de Ireby's Tower and to determine whether they are contemporary with the ceiling of the "prison room" below. Two samples, CRL-D31 and D32, were obtained from this roof. There is evidence, by way of redundant mortices, for the

reuse of a couple of timbers here, and evident splicing-in of modern repair pieces, and such timbers were not sampled.

One of the samples obtained from this roof, CRL-D32, consists of disjointed cores from the same timber, part D32i (an inner portion) and D32ii (an outer portion). The cores from this timber kept on breaking at about the same point and no overlap between the pieces could be obtained. Fortunately each portion had sufficient rings for satisfactory analysis and these are listed and illustrated separately.

de Ireby's Tower - newel stairs roof

Within the walls of the solar of de Ireby's Tower, on its north side, is a newel staircase, roofed by a small covering dome with a basal diameter of about two metres. The roof of this dome consists of a cross-beam, which supports a short central strut or king post. From the central king post radiate eight short principal rafters which run down to curved lengths of wall plate. It is believed that this roof dates to the late fourteenth-century construction of de Ireby's Tower and sampling was requested to establish its date more reliably. Nine samples, CRL-D19 - D27, were obtained from the timbers here.

de Ireby's Tower - first-floor hall, service area, and kitchen roofs

The roofs of the first-floor hall, and the adjacent service area and kitchen are identical to each other and indeed to that of the solar. They again comprise a series of shallow pitched principal rafter trusses with tiebeams, having large common rafters close-set between them. These timbers carry a ridge-beam. A small number of timbers in this roof also show evidence, by way of redundant mortices, of possible reuse. Other timbers, tiebeams for example, have had more modern pieces spliced into them. Twelve samples, CRL-D34 - 45, were obtained from these roof timbers. Once again any possibly reused and apparently modern timbers were not sampled.

de Ireby's Tower, portcullis

Fragmentary traces of a portcullis can be seen, exposed in a partial brick opening, over the outer archway, above the main gates. Sampling of these few visible timbers was commissioned in order to establish whether or not the extant portcullis is the original, fourteenth-century, example, or whether it is a later piece. The portcullis slot was later blocked, and determining a date for the portcullis might establish a *terminus post quem* for this act. Other portcullis timbers may be hidden behind the brickwork in this area. Four core samples were obtained from these timbers, samples CRL-D28 – D31.

de Ireby's Tower - main gates

The main gate to the Castle is located in the outer archway of the gatehouse. The gate comprises heavy double-leafed doors each door being made up of two

layers of thick oak planks clinched with large rivets (see Fig 4). The purpose of sampling was to establish how much, if any the timberwork was original late fourteenth-century material, or at what dates repairs to the doors might have been undertaken.

Samples could not be obtained from either leaf of the main gate. This was in large measure due to the fact that one leaf of the main gate appeared to be locked and welded into the open position, while the other leaf was held open by nuts and bolts which could not be undone at the time of sampling. This made it impossible to clearly view both faces of each door and access the obscured, inner timbers. In such circumstances it was felt ill-advised to core without knowing what obstacles or dangers lay hidden. In the present open position it would have been impossible to obtain sufficient worthwhile samples for satisfactory analysis. This was a particular problem with the main gates given that the growth rings of the visible timbers appeared to be wide and the correct angle of coring would have been crucial if the doors were not to be unduly damaged by coring. A further problem with sampling here is that the narrow gateway is in use for vehicular traffic and the constant passage of this while coring would have caused some difficulties.

Keep stairs

The position of the Keep is to be seen further to the east of de Ireby's Tower in Figure 2. On stylistic and documentary evidence the Keep and the adjoining forebuilding is believed to date to the early twelfth century. Sampling of the timber boards visible in the ceiling of the intramural stairs between the ground and first floor of the Keep was requested to determine the date of this ceiling and to establish if any subsequent repairs or alterations had been made to it.

The boards of this ceiling are set in mortar and stone, and very close to each other, edge to edge, with only their undersides being visible. It was thus difficult to determine how thick the boards were, or where the sapwood or centres on them lay and it was not always possible to core at the optimum angle. Ten cores were obtained from the ceiling boards of the Keep stairs, samples CRL-D01 - 10.

West postern gate

The postern gate in the west curtain wall consists of an oak door (see Fig 5) set in an opening cut through the wall. Dating was requested to establish when this gate might have been created. Although this gate could be opened samples could not be obtained from the boards because they were close set, edge to edge so that no easy angle of coring was possible. Furthermore some of the boards appeared to have wide, and thus low numbers of, growth rings.

Analysis

Each of the 45 samples obtained was prepared by sanding and polishing. It was seen at this point that all four samples from the portcullis timbers had far less than the minimum of 54 rings required for satisfactory tree-ring analysis and

these were rejected. The annual growth-ring widths of the remaining 41 samples were measured, the data of these measurements being given at the end of the report. These date were then compared with each other by the Litton/Zainodin grouping procedure (see appendix) and at a minimum *t*-value of 4.5 two groups of cross-matching samples could be formed.

The first group consists of samples from 33 timbers, which were combined at their indicated offsets to form CRLDSQ01, an unusually long site chronology of 479 rings. The relative positions of the samples in this site chronology are shown in the bar diagram Figure 9.

Site chronology CRLDSQ01 was compared with a large number of reference chronologies for oak indicating a series of high *t*-value cross-matches when the date of its first ring is AD 968 and the date of its last ring is AD 1446. Evidence for this dating is given in the *t*-values of Table 2.

The second cross-matching group comprises two samples. These samples were combined at their indicated offsets to form site chronology CRLDSQ02, of combined overall length 124 rings. The relative positions of the samples in site chronology CRLDSQ02 are shown in the bar diagram Figure 10. Site chronology CRLDSQ02 was compared with a large number of reference chronologies for oak indicating a series of satisfactory *t*-value cross-matches when the date of its first ring is AD 900 and the date of its last ring is AD 1023. Evidence for this dating is given in the *t*-values of Table 3.

Each site chronology was then compared with the other, and with the remaining six measured but ungrouped samples. There was, however, no further cross-matching. Each of the five remaining ungrouped samples was then compared individually with a full range of relevant reference chronologies for oak but again no satisfactory cross-matching was indicated. This analysis is summarised below.

Site chronology	Number of timbers	Number of rings	Date span (where dated)
CRLDSQ01	33	479	AD 968 - AD 1446
CRLDSQ02	2	124	AD 900 - AD 1023
	6		undated
	4		unmeasured

Interpretation

Analysis by dendrochronology has produced two dated site chronologies. The first comprises samples from 33 timbers with a combined overall length of 479 rings. This site chronology is dated as spanning the years AD 968 to AD 1446. The second site chronology comprises two samples. These have a combined overall length of 124 rings and are dated as spanning the years AD 900 to AD

1023. The dated material represent timbers in all areas sampled and analysed, the dated samples being shown, sorted by location, in the bar diagram Figure 11.

The Keep - stairs

The earliest material appears to be that from the ceiling of the keep stairs, represented by samples CRL-D09 and D10, in site chronology CRLDSQ02. Neither of these samples appears to have a definite heartwood/sapwood boundary, this seeming to have been lost due to the rotting of the wood buried in the masonry of the ceiling. It is thus not possible to calculate with reliability the felling date range of the timber represented. It is unlikely, however, that they were felled before about AD 1038, such a date being based upon a 95% confidence limit for the minimum amount of sapwood on mature oaks from this part of England of 15 rings, and of course the felling date could be much later.

It is possible, however, to estimate the felling date range of another group of timbers from the ceiling of the Keep stairs. Five of the seven other dated samples, CRL-D01, D02, D03, D04, and D05, from these timbers in site chronology CRLDSQ01, do appear to retain the heartwood/sapwood boundary, this being very consistent and indicative of a single phase of felling. The average date of the heartwood/sapwood boundary on these five samples is AD 1120. Using a 95% confidence limit for the minimum amount of sapwood on mature oaks from this part of England of 15 rings and a maximum of 40 rings, would give the timbers represented by these samples an estimated felling date in the range AD 1135 to AD 1160.

de Ireby's Tower - "prison room" ceiling

One sample from the joists of the "prison room" ceiling, CRL-D18, retains complete sapwood, that is it has the last ring produced by the tree it represents before it was felled. This last measured complete sapwood ring is dated to AD 1391 and this is thus the felling date of the tree.

The relative position and date of the heartwood/sapwood boundary on sample CRL-D18 is, however, much later than that found on the other dated samples from the "prison room" ceiling. The average heartwood/sapwood boundary date on the other five samples from this ceiling where it exists is AD 1335; on sample CRL-D18 the heartwood/sapwood boundary is dated to AD 1366. This would suggest that, while the timber represented by sample CRL-D18 was certainly felled in AD 1391, the others may have been felled earlier. Using a 95% confidence limit of 15 - 40 sapwood rings on mature oaks would give these other timbers an estimated felling date in the range AD 1350 to AD 1375.

de Ireby's Tower - solar roof

One sample from the solar roof, CRL-D33 retains complete sapwood, with a last measured complete sapwood ring date of AD 1380. This is thus the felling date of the tree represented. The relative position of the heartwood/sapwood

boundary on the other sample from this roof is consistent with it being felled in AD 1380.

de Ireby's Tower - newel stairs roof

Unfortunately, none of the samples from the roof of the newel stairs of the solar retains the heartwood/sapwood boundary. It is thus not possible on the basis of tree-ring analysis to be certain when the timbers they represent were felled. It does seem probable, however, that some might have been felled at different times. Sample CRL-D26, for example, has the latest last-measured heartwood ring date, AD 1446. Using the usual 95% confidence limit for the minimum amount of sapwood on mature oaks from this part of England, 15 rings, would mean that the timber represented is unlikely to have been felled before AD 1461.

Sample CRL-D24, on the other hand, has the earliest last-measured heartwood ring date of this set of timbers, AD 1161. Allowing that the centre of the tree is not present on the sample it would have to have had in excess of 500 rings if it too were felled in AD 1461. This would represent an exceptionally long-lived tree and is somewhat unlikely.

The last-measured ring dates of the other two dated samples from the newel stairs roof are intermediate between these two extremes. Given the long-lived nature of the trees used at this site it is possible that the timbers they represent were also cut in the late-fifteenth century, the trees perhaps being in excess of 200 or 300 years of age when felled.

de Ireby's Tower - first-floor hall, service area, and kitchen roofs

Samples from four timbers of the hall and kitchen roofs of de Ireby's Tower retain complete sapwood. In each case the last-measured, complete, sapwood ring date is the same, AD 1380. This is thus the felling date of the timbers represented. The relative position of the heartwood/sapwood boundary on the other samples from these roofs are consistent with their being felled in AD 1380 also.

However, it may be noticed from the bar diagrams Figures 9 and 11, that the relative position of the heartwood/sapwood boundaries on the two samples from the roof of the service area, where it exists on CRL-D40 and 42, is somewhat later than on samples from the hall, kitchen, and solar roofs, and the ceiling of the "prison room". This point is emphasised in Table 1 where the dates of the heartwood/sapwood boundaries of CRL-D40 and 42 are noticeably later than most of those from de Ireby's Tower. Indeed the heartwood/sapwood boundary dates on CRL-D40 and D42 are very close to that seen on sample CRL-D18, from the "prison room" ceiling, which is known to have been felled in AD 1391. Using a 95% confidence limit of 15 to 40 sapwood rings would give the timbers represented by samples CRL-D40 and D41 an estimated felling date in the range AD 1382 to AD 1407.

It must thus be considered a possibility that, while the timbers represented by samples CRL-D40 and D42 could have been felled at the same time as the

others from the hall and kitchen area in AD 1380, the roof of the service area is later.

Conclusion

The Keep

The earliest material found in this programme of analysis are two boards, represented by samples CRL-D09 and D10 in site chronology CRLDSQ02, with a last measured ring date of AD 1023. Because of the lack of a definite heartwood/sapwood boundary it is not possible to say with certainty when the timbers represented were felled. Given a minimum of 15 sapwood rings it is, however, unlikely that they were cut before about AD 1038. It is thus possible that these samples represent timbers that were originally used in the construction of the first Norman fortification here, begun by William II, in AD 1092 and subsequently reused in alterations to the ceiling of the Keep stairs. This is, however, by no means certain. It is equally possible that the samples represent the inner portions of long-lived trees that were felled in the twelfth century, or indeed, even later.

A group of other timbers from the ceiling of the Keep stairs, represented by samples CRL-D01 – D07, have a felling date in the range AD 1135 - 60. Such a range is generally consistent with the supposed date of the Keep, which is known to have been begun by Henry I in AD 1122. It is perhaps more likely though that these timbers were felled during the occupation of Carlisle Castle by King David I of Scotland, AD 1136 - 57, and he completed the Keep. However, it is perhaps possible that these samples represent work done after the Castle was restored to the English in AD 1157. It is known that building work on the new wall and gatehouse was undertaken between AD 1167 – 8.

de Ireby's Tower

The samples from the hall, kitchen, and solar roofs of de Ireby's Tower, and of almost all those from the ceiling of the "prison room" appear to represent timbers felled in, or very close to, AD 1380. Such a date is highly consistent with the completion date of AD 1383 intimated by the documentary sources. The tree-ring analysis thus shows that at least some parts of de Ireby's Tower are contemporary with each other.

It is possible that the two timbers from the roof of the service area, represented by samples CRL-D40 and D42, could have been felled *c* AD 1380, and that it too is contemporary. However, it is possible that these two timbers, as well as that represented by sample CRL-D41, were felled later. At the time of sampling no stylistic or structural evidence for any break or discontinuity between the roofs of de Ireby's Tower was noticed, and these potentially later timbers may represent alterations or repairs undertaken after the main body of work was complete. The only way of determining this conclusively might be to take further samples from this area.

One timber from the ceiling of the "prison room" was, however, certainly felled later than the majority of others, in AD 1391. This may relate to an alteration or repair. Tree-ring dating would thus suggest that the documentary information on this area of construction of the Tower is correct, and while part of the stonework might be of twelfth-century date the majority of the Tower dates to the later fourteenth century.

The latest material found in this analysis appears in the roof of the newel stairs on the north side of the solar. The latest timber used here is unlikely to have been felled before AD 1461 and might have been felled much later. Given that timber with possibly earlier felling dates potentially centuries earlier has also been found in this roof, this could suggest that older timber has been reused in this roof during some fifteenth- or possibly early sixteenth-century repair phase. The most likely possible historic context for these repairs might be the damage caused in AD 1461 when dispossessed Lancastrians and Scots joined together and revolted against the Yorkists who held the town.

Of the 41 measured samples, six, CRL-D08, D19, D21, D22, D25, and D27, remain undated. Two of these samples have low, though statistically valid, numbers of rings. The other four samples have greater ring counts, but all show bands of narrow rings, possibly brought on by stress. It is possibly these factors that make cross-matching and dating difficult.

A number of observations might be made about the material obtained and analysed from the Castle. The first is the long-lived nature of some of the trees. In tree-ring dating it is not very common to find trees that lived to be more than 200 to 250 years of age when felled. Yet from Carlisle Castle we have a number of samples that are from trees that probably lived for about 400 years before being cut, and were possibly even older.

A second observation is the early date of the inner-most rings on some of the samples and thus the early date of seeding or first growth of some of the trees. Sample CRL-D24 has a first ring date of AD 969, and D17 a first ring date of AD 977. Given that the samples do not include the centres of the trees, the trees they represent probably began growing in the middle of the tenth century AD. This is not as early, however, as the trees, or possibly tree, represented by samples CRL-D09 and D10. Estimating that on sample D10 the centre of the tree is some 20 - 30 rings away, and that the innermost existing ring on the sample is dated to AD 900, this would suggest that the tree represented began growing around AD 870 - 80.

Both these features, longevity and early tree growth, are seen in many other timbers from Carlisle analysed by this and other laboratories, in particularly the medieval Carlisle Guildhall (Howard *et al* 1994), the nave roof of Carlisle Cathedral (Howard *et al* 2001), and The Lanes, Carlisle (Groves 1996). Indeed, as will be seen from Table 2, site chronology CRLDSQ01 from the Castle cross-matches exceptionally well with the reference material from both these sites. So high is the value of the cross-matching in fact, *t*-values of 23.0 and 17.5 being seen, as to suggest that the timbers used in all three sites came from the same source. The site of this woodland is of course unknown but it is possible that a search of the documentary material might reveal its location. These observations

might suggest that medieval builders in Carlisle had access to quantities of high quality woodland, perhaps remnants of ancient or "wild" woods.

As in many cases with the use of timber, there is apparently a very strong local folk tradition that the timbers used in the "prison room" ceiling are reused from ships. This belief is based on the fact that the beams are large and some are very slightly curved. Given that Carlisle is very close to the Solway this at least has a very slightly greater than normal chance of being a possibility, as must the possibility of the timbers being imported from somewhere further afield in Britain or indeed from abroad.

However, given that so many timbers from up to four Carlisle sites cross-match so well with each other and are almost certainly from the same general woodland source, it is almost certain that the timbers of the "prison room" ceiling of de Ireby's Tower are not ships' timbers. It is also very unlikely that they are imported. As is so often the case, the use of ships' timbers in old buildings is simply a folk tradition.

If at any time in the future the ceiling boards of the Keep stairs are removed for conservation, or the surrounding mortar is cleared out, further sampling of these should certainly be considered. Given that samples with very early last ring dates have been found it may well be possible to show how extensive is the reuse of such early timbers. Further coring might also provide early samples with certain sapwood, or at least the heartwood/sapwood boundary.

Should conservation of the postern or main gates ever be undertaken, or at any time either leaf of the main gates be moved, an examination should also be made of these, and the sampling of the doors be considered again.

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Table 1: Details of samples from Carlisle Castle, Carlisle, Cumbria

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	The Keep - stairs ceiling					
CRL-D01	Step 3 (from bottom)	107	h/s	AD 1012	AD 1118	AD 1118
CRL-D02	Step 2	81	h/s	AD 1043	AD 1123	AD 1123
CRL-D03	Step 4	56	h/s	AD 1064	AD 1119	AD 1119
CRL-D04	Step 1	90	h/s	AD 1029	AD 1118	AD 1118
CRL-D05	Step 5	70	h/s	AD 1052	AD 1121	AD 1121
CRL-D06	Step 6	57	no h/s	AD 1029	------	AD 1085
CRL-D07	Step 7	84	no h/s	AD 1016	------	AD 1099
CRL-D08	Step 38	54	no h/s	------	------	------
CRL-D09	Step 41	96	no h/s	AD 902	------	AD 997
CRL-D10	Step 42	124	no h/s	AD 900	------	AD 1023
	de Ireby's Tower – "prison room" ceiling					
CRL-D11	Joist 6 (from east)	332	11	AD 1010	AD 1330	AD 1341
CRL-D12	Joist 7	191	no h/s	AD 1028	------	AD 1218
CRL-D13	Joist 5	340	15	AD 1007	AD 1331	AD 1346
CRL-D14	Joist 8	226	h/s	AD 1108	AD 1333	AD 1333
CRL-D15	Joist 9	182	2	AD 1161	AD 1340	AD 1342
CRL-D16	Joist 2	366	25	AD 1000	AD 1340	AD 1365
CRL-D17	Joist 3	360	h/s	AD 977	AD 1336	AD 1336
CRL-D18	Joist 13	278	26C	AD 1114	AD 1366	AD 1391

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	de Ireby's Tower – newel stairs roof					
CRL-D19	East – west crossbeam	63	no h/s	------	------	------
CRL-D20	South west rafter	103	no h/s	AD 1195	------	AD 1297
CRL-D21	South east rafter	96	h/s	------	------	------
CRL-D22	East rafter	66	no h/s	------	------	------
CRL-D23	North rafter	155	no h/s	AD 1143	------	AD 1297
CRL-D24	North east rafter	214	no h/s	AD 968	------	AD 1181
CRL-D25	King post	54	3	------	------	------
CRL-D26	West wall plate	244	no h/s	AD 1203	------	AD 1446
CRL-D27	South rafter	65	h/s	------	------	------
	de Ireby's Tower – portcullis					
CRL-D28	Cross-rail	nm	---	------	------	------
CRL-D29	Stud post	nm	---	------	------	------
CRL-D30	Stud post	nm	---	------	------	------
CRL-D31	Main post	nm	---	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	de Ireby's Tower - solar roof					
CRL-D32i	South purlin, bay 1 (part 1)	114	no h/s	AD 1053	------	AD 1166
CRL-D32ii	South purlin, bay 1 (part 2)	154	h/s	AD 1194	AD 1347	AD 1347
CRL-D33	South common rafter 1, bay 2	157	25C	AD 1224	AD 1355	AD 1380
	de Ireby's Tower - hall roof					
CRL-D34	North purlin, bay 4	86	no h/s	AD 1143	------	AD 1228
CRL-D35	North common rafter 4, bay 4	247	51C	AD 1134	AD 1329	AD 1380
CRL-D36	South common rafter 5, bay 4	225	42C	AD 1156	AD 1338	AD 1380
CRL-D37	South common rafter 3, bay 5	207	37	AD 1186	AD 1335	AD 1372
CRL-D38	South common rafter 4, bay 5	126	10	AD 1248	AD 1363	AD 1373
	de Ireby's Tower - service area roof					
CRL-D39	North purlin, bay 6	109	45	AD 1266	AD 1329	AD 1374
CRL-D40	South purlin, bay 6	155	h/s	AD 1212	AD 1366	AD 1366
CRL-D41	South rafter 1, bay 7	220	no h/s	AD 1051	------	AD 1270
CRL-D42	South rafter 2, bay 7	141	h/s	AD 1227	AD 1367	AD 1367

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	de Ireby's Tower - kitchen roof					
CRL-D43	South rafter 1, bay 8	98	no h/s	AD 1186	------	AD 1283
CRL-D44	North rafter 3, bay 8	94	23C	AD 1287	AD 1357	AD 1380
CRL-D45	North rafter 4, bay 9	137	24C	AD 1244	AD 1356	AD 1380

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

Table 2: Results of the cross-matching of chronology CRLDSQ01 and relevant reference chronologies when the date of the first ring is AD 968 and the last ring date is AD 1446

Reference chronology	Span of chronology	*t*-value	
East range, Carlisle Guildhall, Cumbria	AD 976 – 1382	23.0	(Howard *et al* 1994)
Carlisle Cathedral	AD 961 – 1374	17.5	(Howard *et al* 2001)
Royal Oak Cottage, Moorhouse, Cumbria	AD 1095 – 1362	14.7	(Howard *et al* 1998)
Moorhouse Barn, Burgh by Sands, Cumbria	AD 1053 – 1434	12.8	(Esling *et al* 1989)
South range, Carlisle Guildhall, Cumbria	AD 1054 – 1397	11.2	(Howard *et al* 1994)
England	AD 401 – 1981	9.7	(Baillie and Pilcher 1982 unpubl)
Scotland	AD 946 – 1975	8.8	(Baillie 1977)
East Midlands	AD 882 – 1981	8.4	(Laxton and Litton 1988)

Table 3: Results of the cross-matching of chronology CRLDSQ02 and relevant reference chronologies when the date of the first ring is AD 900 and the last ring date is AD 1023

Reference chronology	Span of chronology	*t*-value	
Scotland	AD 946 – 1975	6.4	(Baillie 1977)
St Hugh's Choir, Lincoln Cathedral	AD 882 – 1191	5.4	(Laxton and Litton 1988)
Ely Cathedral, Cambs	AD 903 – 1159	5.3	(Howard *et al* unpubl (a))
Hemmington, Leics	AD 888 – 1087	5.3	(Howard *et al* unpubl (b))
London Fleet Valley	AD 745 – 1226	5.2	(Tyers and Hibbard 1993)
London FW	AD 802 – 1345	5.0	(Tyers unpubl)
East Midlands	AD 882 – 1981	5.0	(Laxton and Litton 1988)
Carlisle Cathedral	AD 961 – 1374	5.0	(Howard *et al* 2001)

Figure 1: Map to show general location of Carlisle Castle

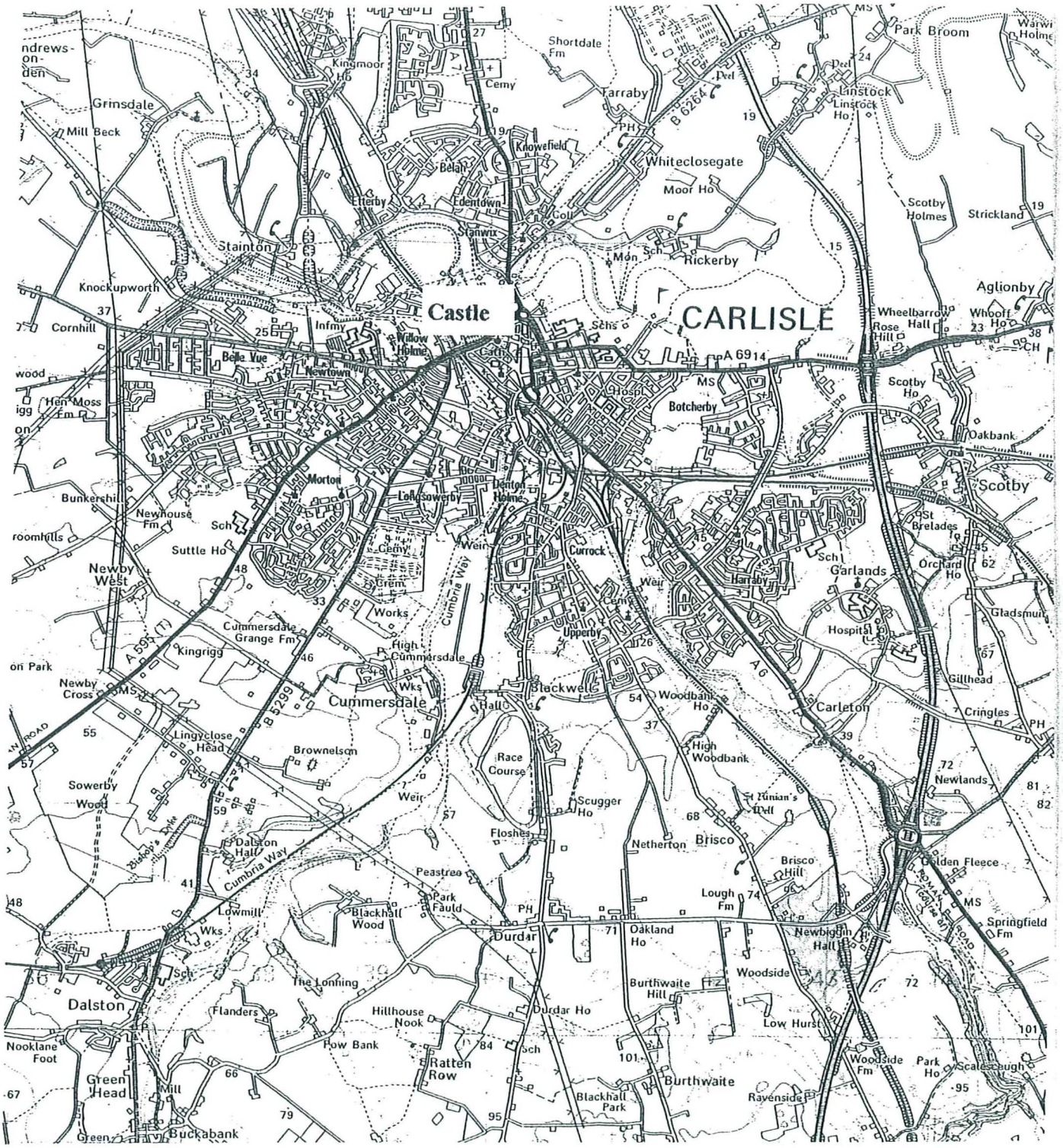


Figure 2: General plan of Carlisle Castle to show areas of sampling

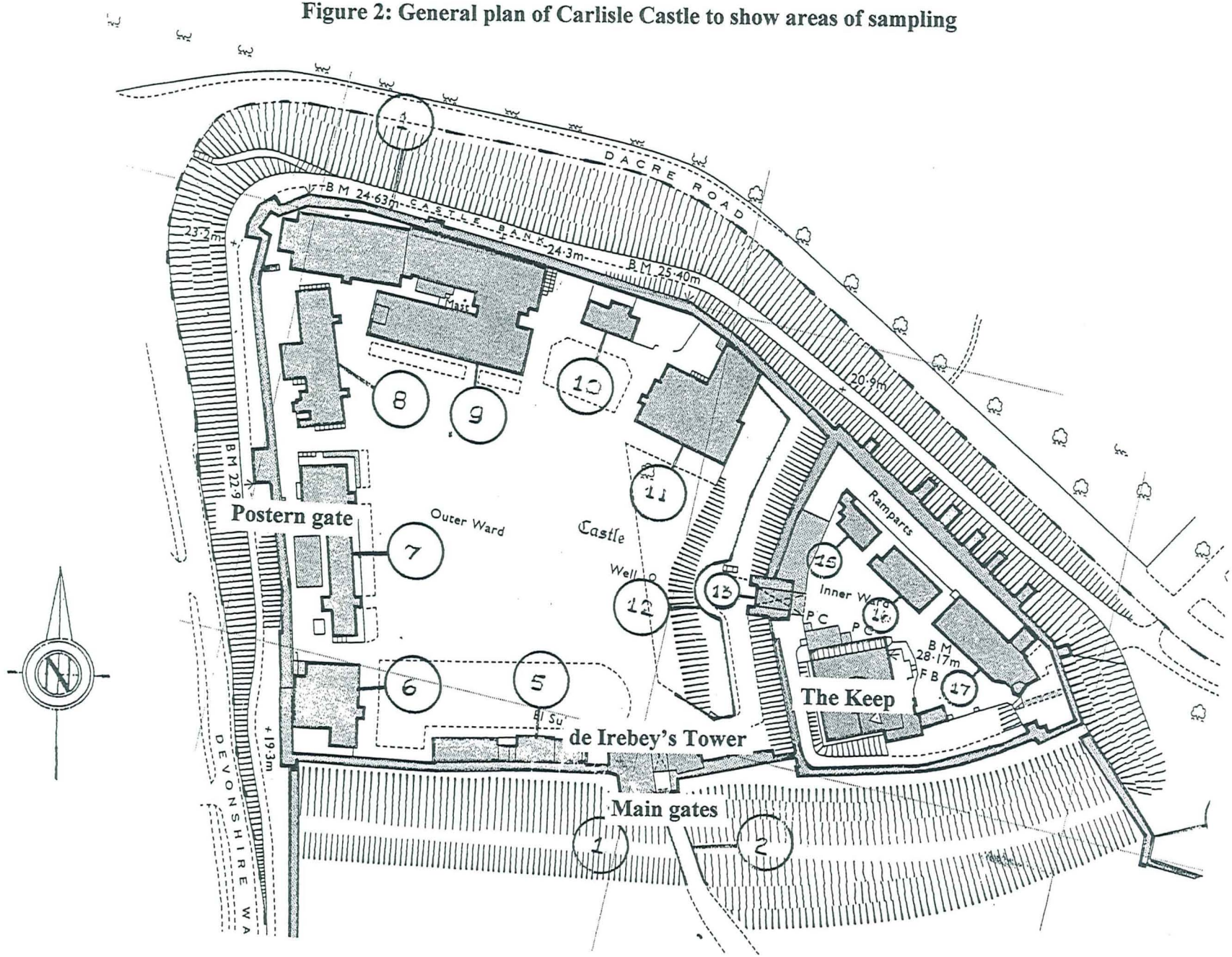


Figure 3: Plan of de Ireby's Tower
(first floor above, ground floor below)

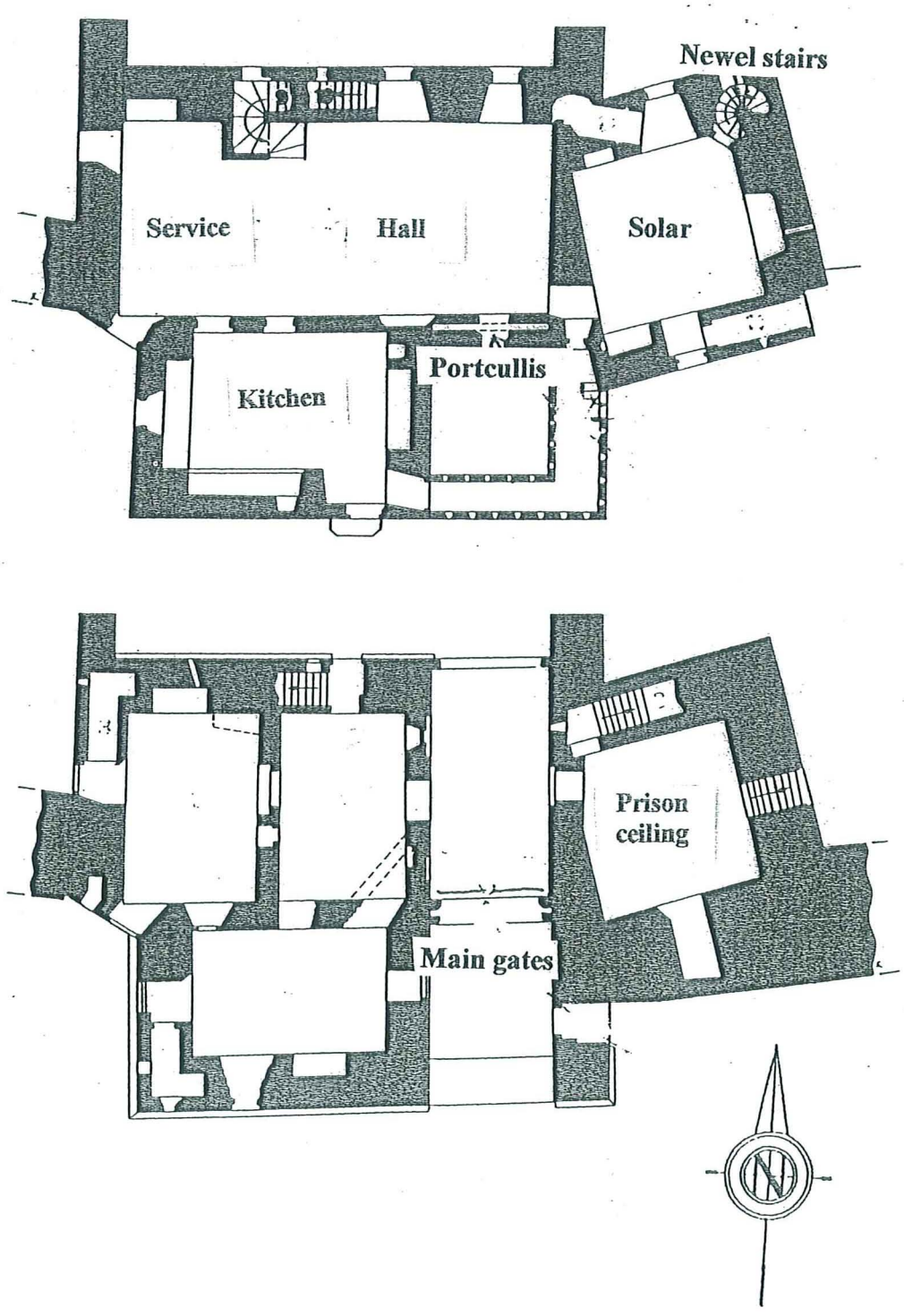


Figure 4: Inner face of the main gates

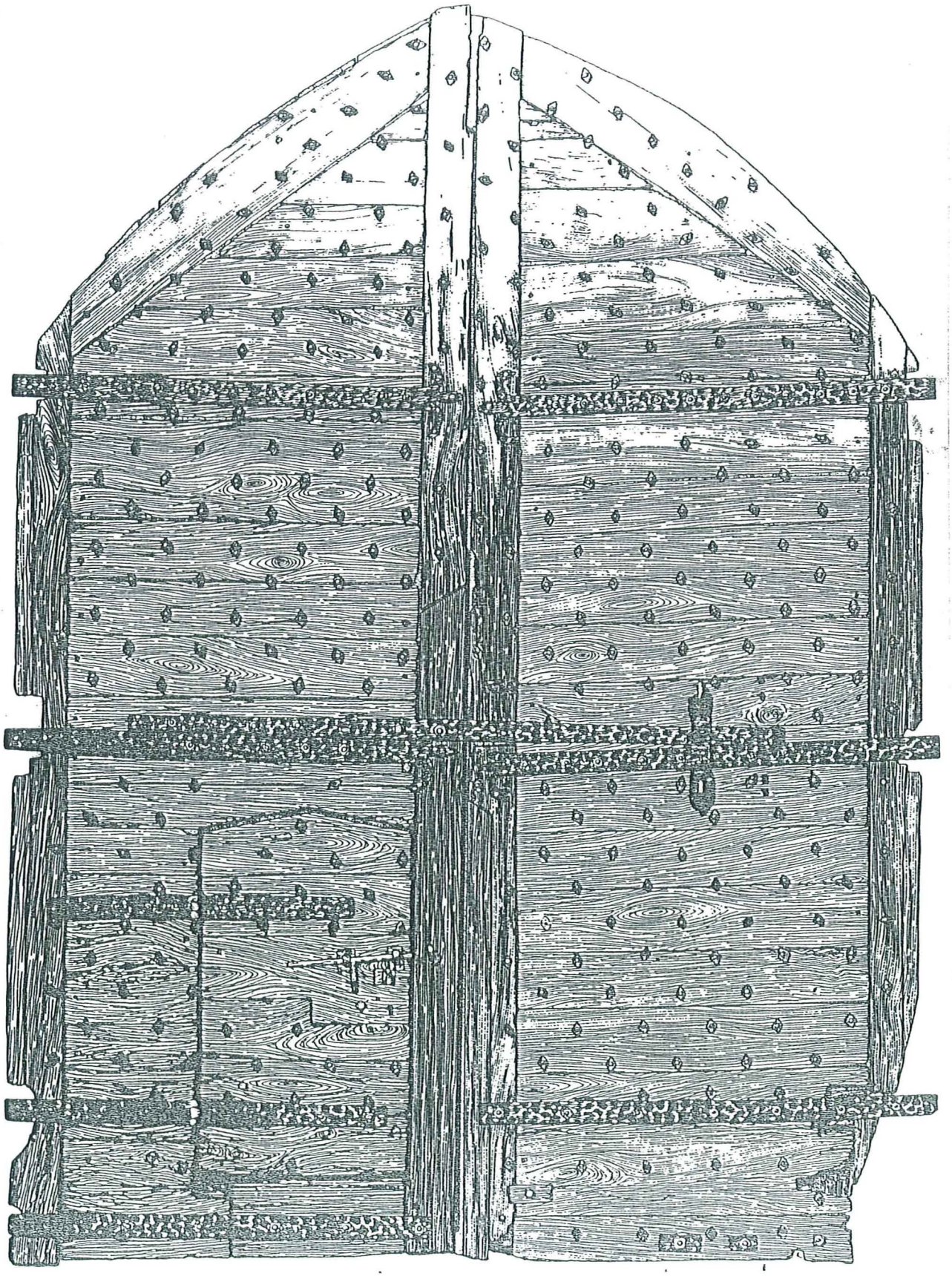


Figure 5: The postern gate
(outer face to left, inner face to right)

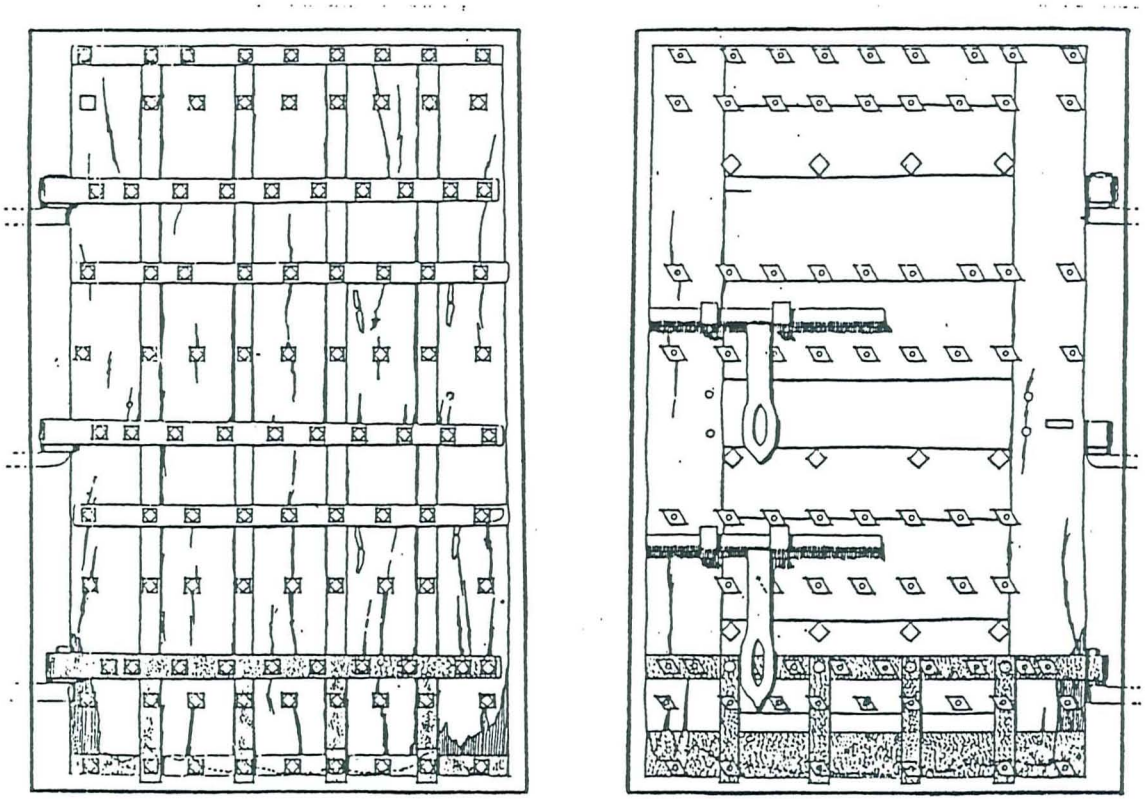


Figure 6a: The Keep to show approximate position of samples from the stair ceiling boards

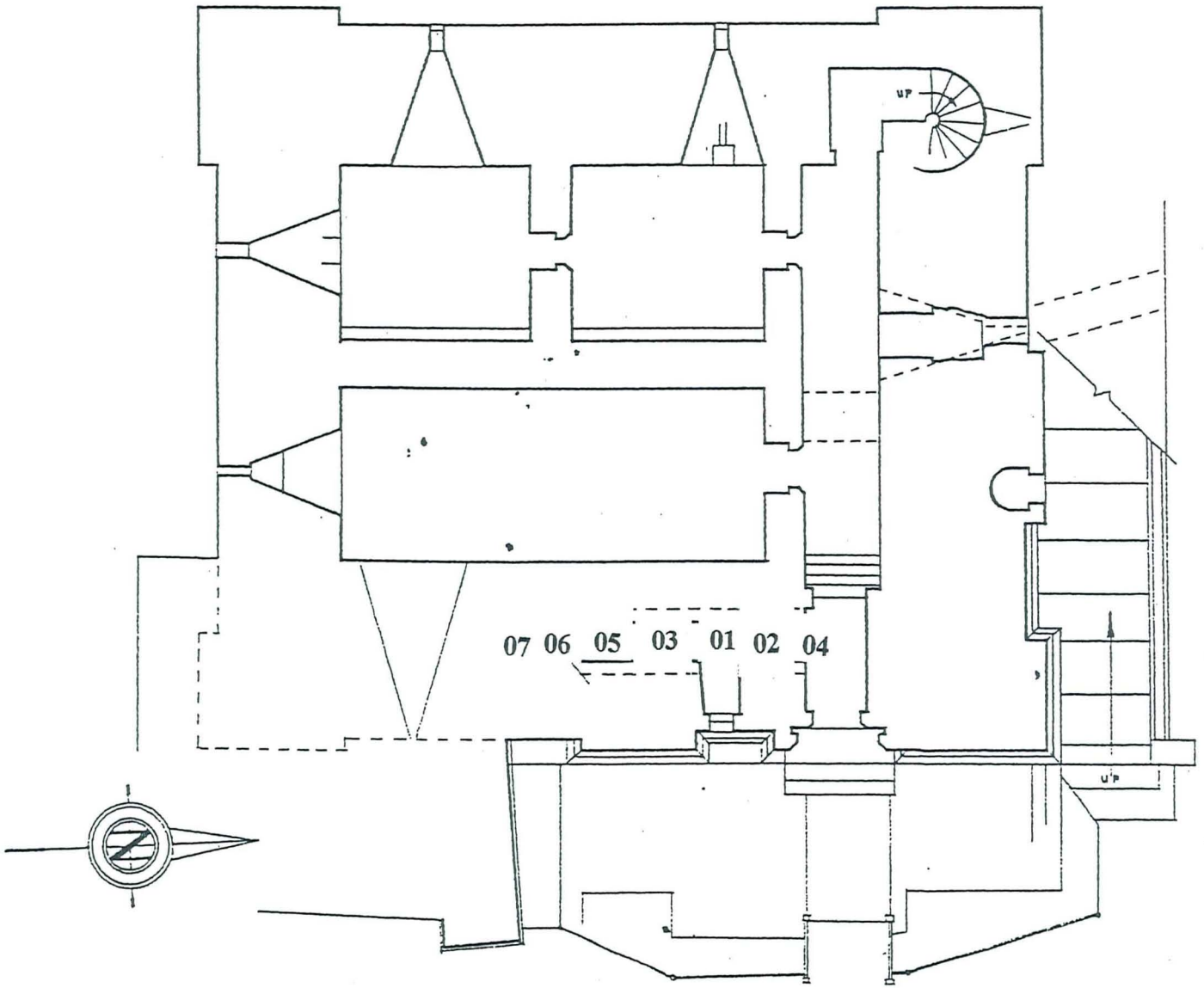


Figure 6b: The Keep to show approximate position of samples from the stair ceiling boards

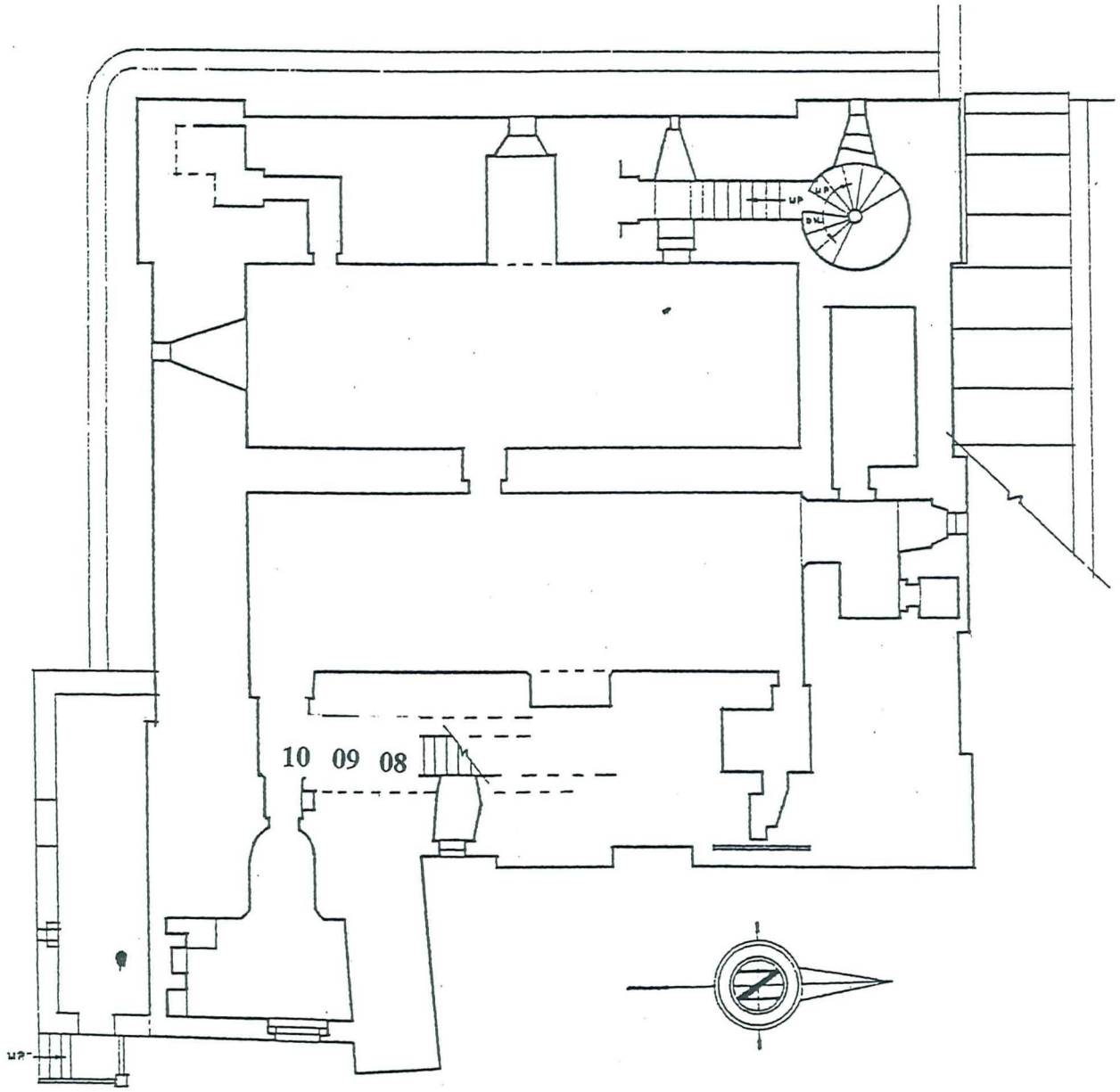


Figure 7a: De Ireby's Tower to show approximate position of sampled timbers from the ceiling of the prison room

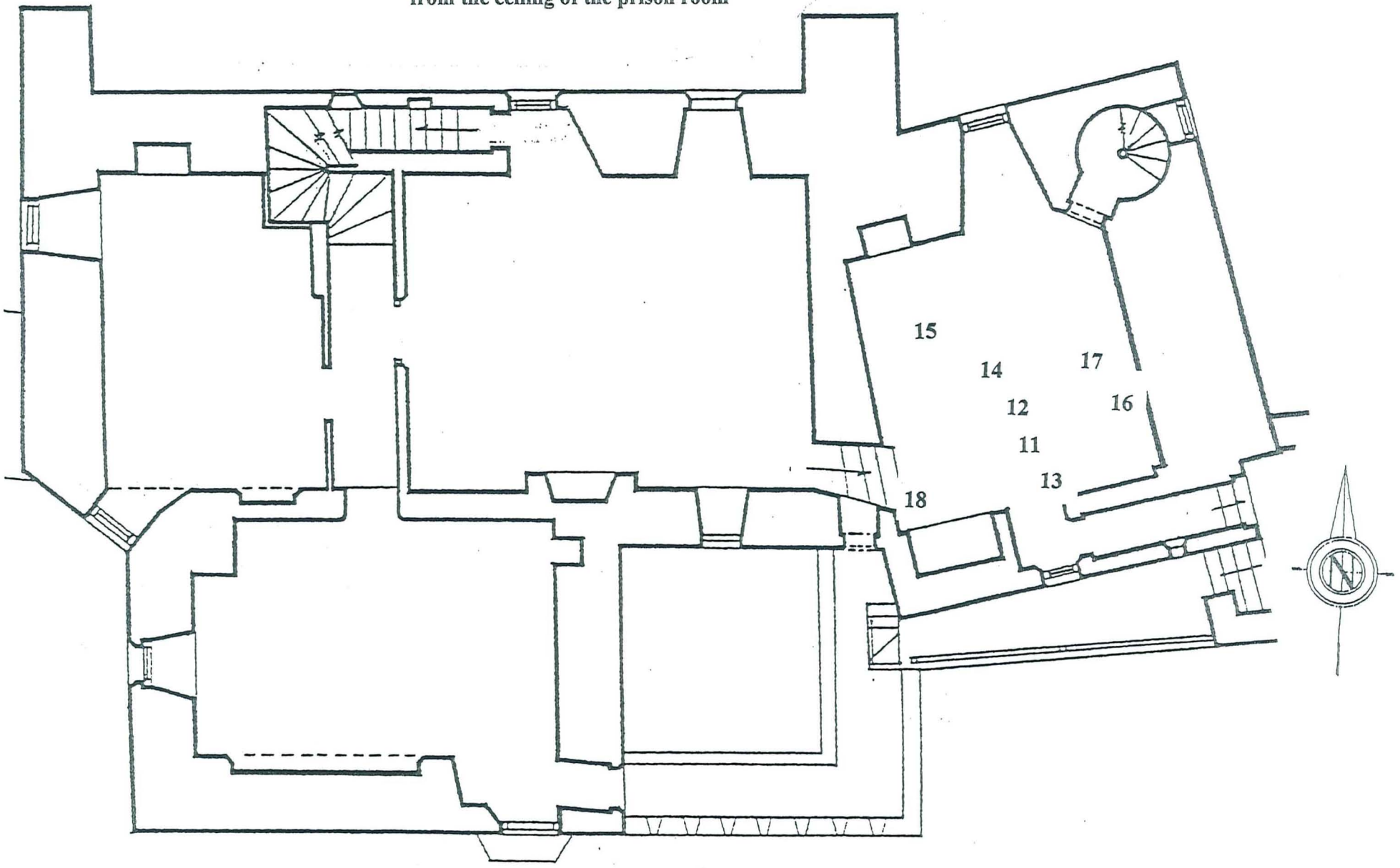


Figure 7b: De Ireby's Tower to show approximate position of sampled timbers from the roof of the solar, hall, service room, and kitchen

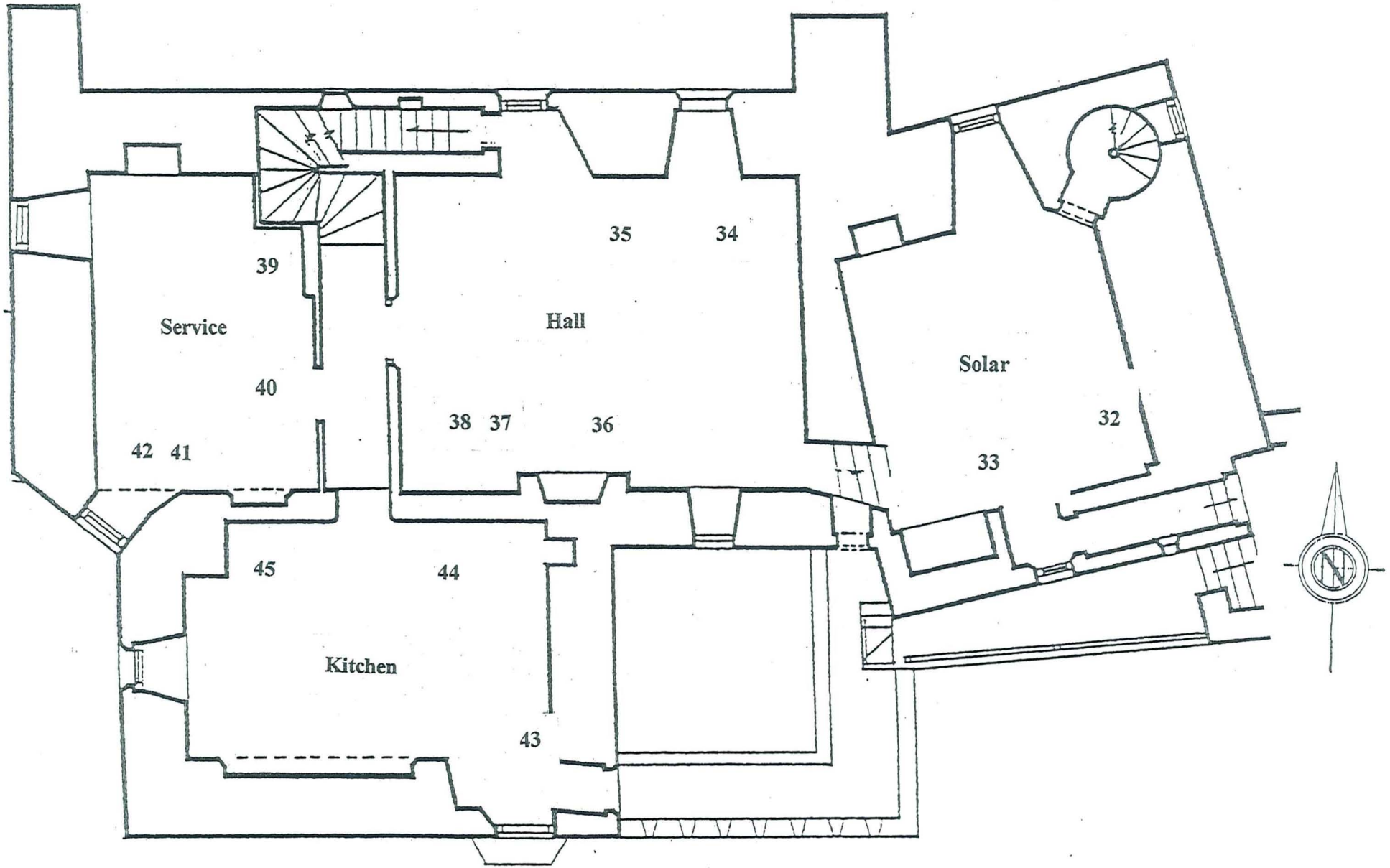


Figure 8: The newel stair roof to show timbers sampled

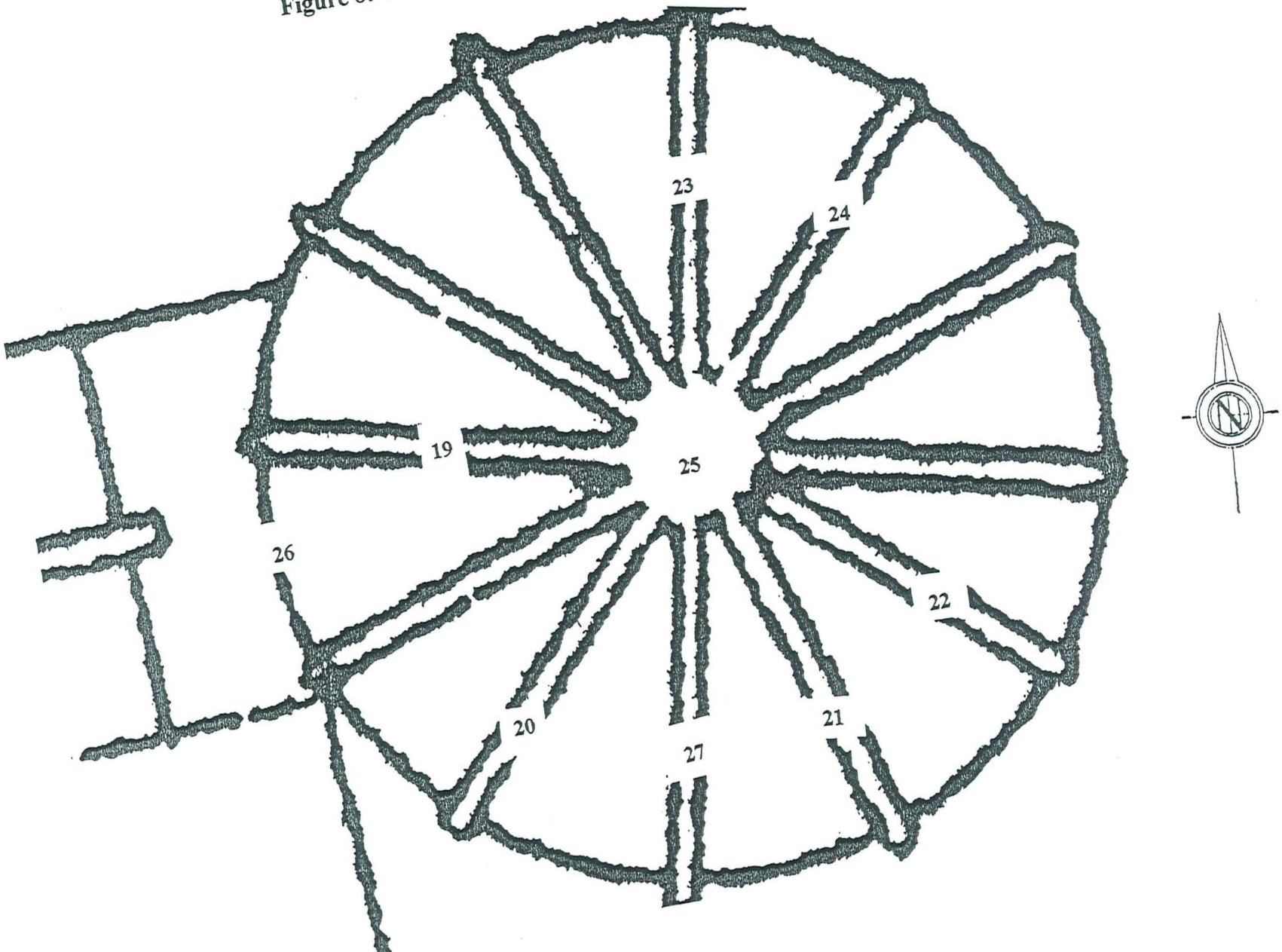
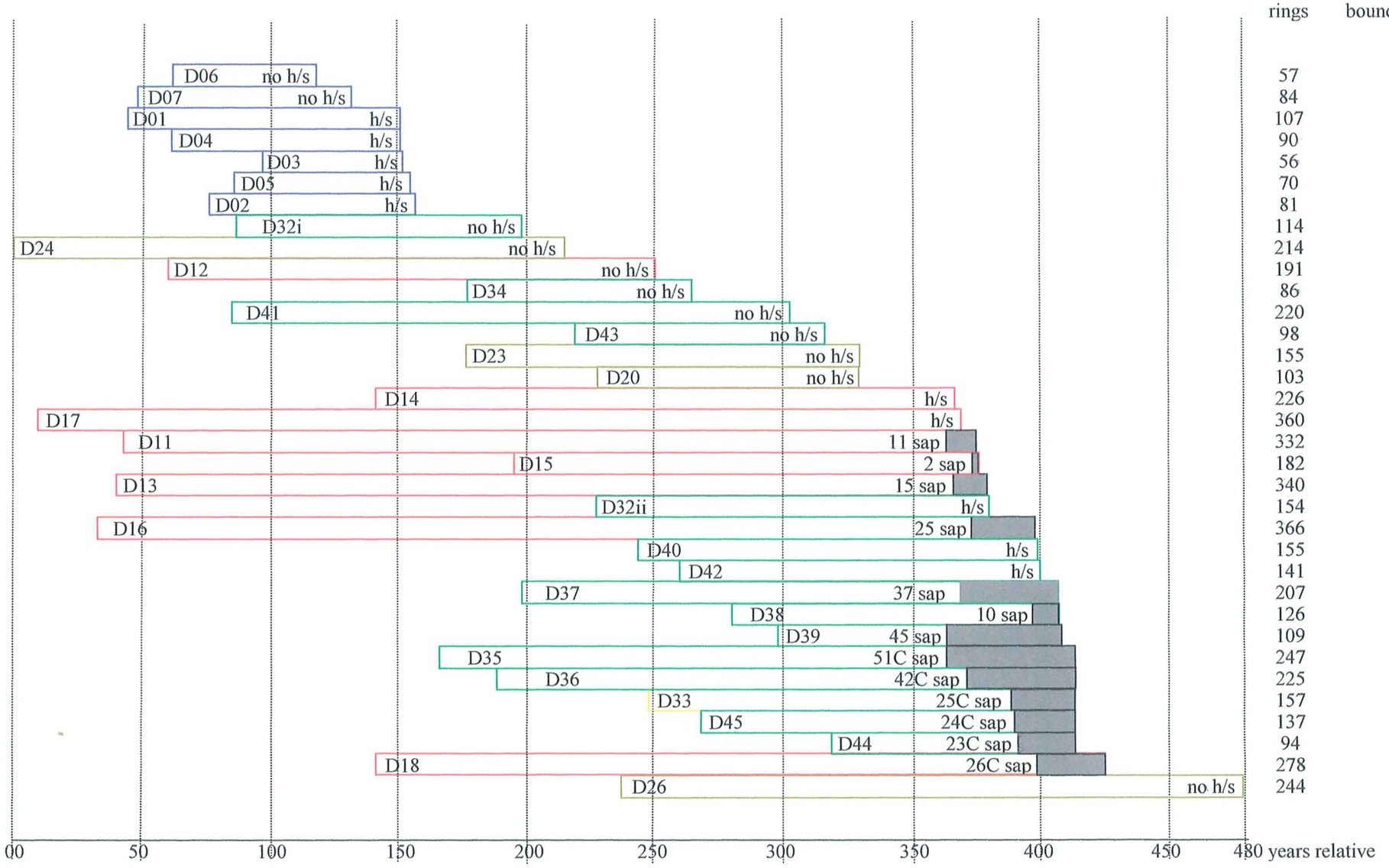


Figure 9: Bar diagram of the samples in site chronology CRLDSQ01 in last measured ring position

Off-set		Total rings	Relative heartwood/sapwood boundary position
61	D06 no h/s	57	---
48	D07 no h/s	84	---
44	D01 h/s	107	151
61	D04 h/s	90	151
96	D03 h/s	56	152
84	D05 h/s	70	154
75	D02 h/s	81	156
85	D32i no h/s	114	199
00	D24 no h/s	214	---
60	D12 no h/s	191	---
175	D34 no h/s	86	---
83	D41 no h/s	220	---
218	D43 no h/s	98	---
175	D23 no h/s	155	---
227	D20 no h/s	103	---
140	D14 h/s	226	366
9	D17 h/s	360	369
42	D11 11 sap	332	363
193	D15 2 sap	182	373
39	D13 15 sap	340	364
226	D32ii h/s	154	380
32	D16 25 sap	366	373
244	D40 h/s	155	399
259	D42 h/s	141	400
198	D37 37 sap	207	368
280	D38 10 sap	126	396
298	D39 45 sap	109	362
166	D35 51C sap	247	362
188	D36 42C sap	225	371
256	D33 25C sap	157	388
276	D45 24C sap	137	389
319	D44 23C sap	94	290
146	D18 26C sap	278	399
235	D26 no h/s	244	---



Samples from the Keep stairs ceiling

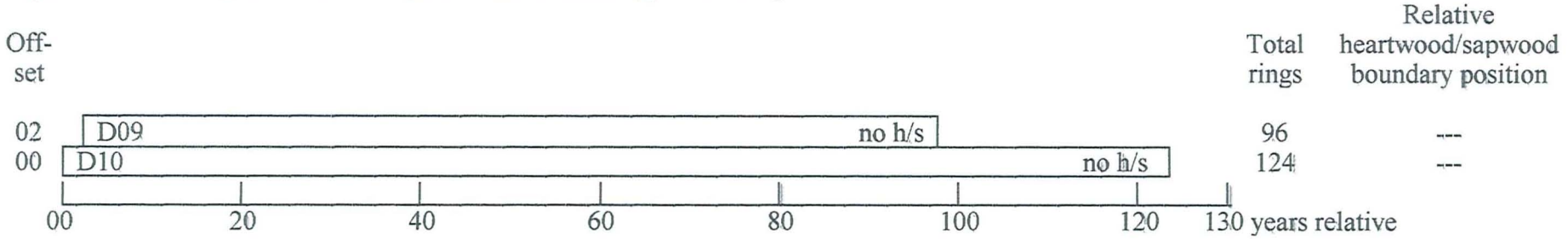
Samples from the newel stairs roof

Samples from the "prison room" ceiling

Samples from roof of de Ireby's Tower

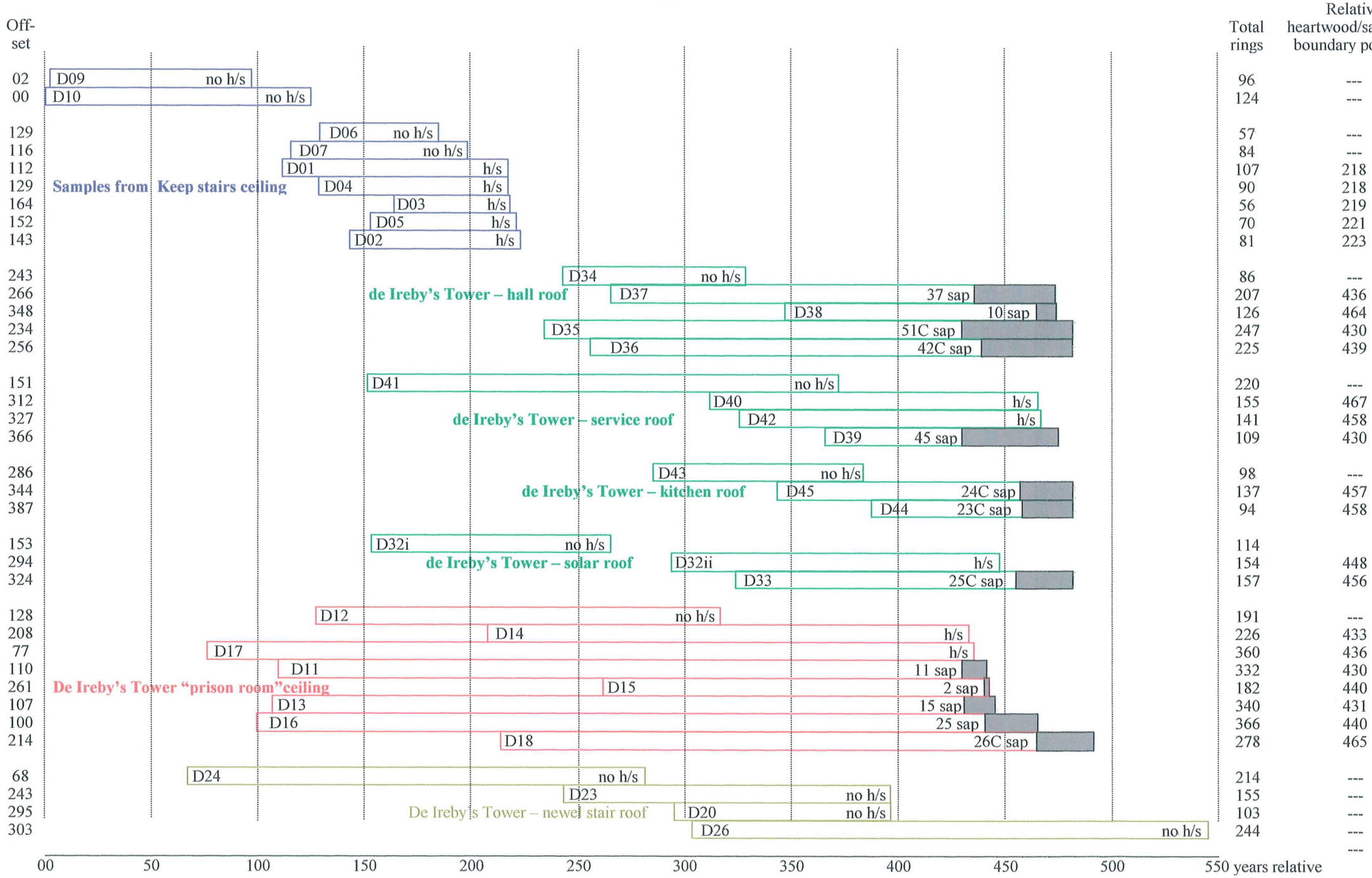
white areas = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample, the last measured ring date is the felling date of the timber

Figure 10: Bar diagram of the samples in site chronology CRLDSQ02



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

Figure 11: Bar diagram of all dated samples sorted by sampling location in last measured ring position



white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample. C = complete sapwood retained on sample, the last measured ring date is the felling date of the timber

Data of measured samples – measurements in 0.01 mm units

CRL-D01A 107
193 278 251 301 169 226 248 227 166 151 111 171 135 54 34 107 133 109 134 84
78 62 60 65 53 64 79 92 63 48 72 50 53 39 88 116 76 67 85 73
50 37 18 21 20 24 23 26 30 32 19 16 19 16 26 40 42 51 37 24
23 21 15 39 44 51 55 35 44 50 27 38 41 48 61 73 55 62 37 55
46 42 27 36 48 49 34 36 41 49 35 38 44 59 51 55 61 68 61 63
95 105 190 163 229 191 169
CRL-D01B 107
237 264 266 292 162 237 246 217 166 151 128 180 131 55 30 104 124 115 134 81
78 70 50 69 54 58 81 91 61 52 65 56 52 42 92 123 67 60 86 62
55 34 26 15 21 23 23 19 34 26 19 20 20 21 18 40 49 51 31 24
19 18 25 38 39 46 58 36 46 44 31 36 42 42 62 72 46 72 36 53
47 38 33 39 44 51 33 38 39 44 36 35 45 59 49 63 59 70 52 53
102 99 181 170 227 187 163
CRL-D02A 81
62 69 61 67 88 70 108 86 80 70 70 56 68 107 128 85 79 97 80 52
54 70 53 86 91 106 151 169 82 86 71 63 127 111 125 117 92 138 93 166
127 103 93 92 128 140 114 92 65 54 50 34 45 53 58 71 97 69 36 39
77 99 99 92 55 104 137 79 48 99 114 126 100 130 116 122 73 95 85 121
91
CRL-D02B 81
57 71 64 67 78 79 101 91 76 70 56 54 84 86 135 92 66 100 79 59
51 64 59 80 90 108 182 200 76 86 76 63 124 113 126 112 99 132 99 166
134 91 100 87 126 149 109 91 66 67 32 39 46 53 50 66 98 65 37 46
68 106 93 87 58 110 133 81 49 85 110 130 103 129 104 120 79 85 89 121
90
CRL-D03A 56
130 69 80 98 95 92 121 58 84 90 91 133 135 126 109 73 118 110 131 117
97 78 91 107 110 102 91 57 58 52 53 63 70 57 69 97 91 44 38 72
82 91 84 50 87 56 35 43 62 66 86 59 83 82 74 62
CRL-D03B 56
116 63 91 91 97 99 123 82 92 94 96 111 118 122 110 81 105 84 117 119
95 74 91 103 105 103 85 79 57 52 62 50 60 66 62 109 90 36 46 69
74 96 84 58 79 60 38 41 59 69 75 81 74 77 79 62
CRL-D04A 90
176 237 315 160 138 155 162 170 189 349 275 220 218 173 151 108 60 53 77 98
74 94 102 82 81 74 89 126 141 123 112 119 65 64 59 114 61 83 129 102
72 145 67 85 70 66 177 119 113 127 85 175 105 237 157 97 104 118 129 156
121 117 90 50 44 41 49 45 47 74 93 73 24 37 83 106 142 103 72 131
135 88 62 93 128 138 84 52 135 138
CRL-D04B 90
178 238 242 183 135 163 178 186 186 311 252 223 221 169 149 94 70 51 86 92
76 88 101 80 87 66 104 112 147 139 108 134 71 62 70 108 69 71 124 106
87 116 62 75 104 71 163 119 96 138 72 166 110 233 166 96 106 103 128 158
117 114 93 52 45 38 45 50 49 66 108 55 29 45 77 114 130 109 81 118
126 90 72 94 126 111 82 57 137 133
CRL-D05A 70
62 69 44 93 78 112 96 88 95 90 61 75 89 73 74 81 66 48 66 59
38 41 66 58 75 83 71 72 93 76 120 118 78 90 90 89 105 76 83 80
63 56 41 52 55 55 70 90 75 54 51 80 122 92 91 62 102 115 61 52
66 80 95 87 109 94 87 49 48 62

CRL-D05B 70
56 91 48 86 76 120 87 87 86 77 61 64 86 86 77 71 66 55 67 50
38 40 55 71 81 60 68 67 100 81 118 96 84 86 88 96 109 73 85 78
99 52 54 58 59 58 78 92 75 40 50 96 104 126 59 73 89 113 60 62
57 75 98 94 109 97 86 49 48 45
CRL-D06A 54
176 229 179 135 195 215 230 221 332 313 246 217 188 205 127 66 38 111 133 197
167 131 100 73 49 34 55 110 120 126 110 145 77 81 54 58 41 64 102 77
51 54 59 38 31 19 45 50 42 56 65 47 52 80
CRL-D06B 57
163 219 173 132 197 213 214 220 307 310 246 206 206 188 130 64 46 104 144 185
184 120 104 71 56 31 61 105 139 110 115 133 85 72 51 65 45 61 97 77
57 51 48 37 31 29 49 47 52 65 50 43 59 72 61 73 100
CRL-D07A 84
179 178 224 272 180 195 234 280 285 246 168 281 330 324 320 367 221 214 207 179
152 217 263 257 208 185 169 130 67 38 36 46 68 34 35 32 34 34 25 30
36 52 67 107 184 88 140 111 94 41 56 102 110 111 133 98 106 28 33 37
102 100 172 114 145 144 182 199 151 165 150 125 101 98 69 72 29 36 38 64
59 70 34 49
CRL-D07B 84
138 176 229 270 201 235 223 268 306 238 186 259 345 312 340 360 220 208 190 174
140 214 271 251 195 189 166 127 59 30 42 47 54 50 35 30 31 34 29 33
31 49 67 114 187 83 134 116 93 33 57 107 106 109 140 92 103 28 36 43
83 109 179 113 129 147 189 198 150 162 140 134 91 105 62 65 44 32 39 57
61 63 35 55
CRL-D08A 54
127 129 115 106 97 112 135 113 176 166 98 123 126 107 78 68 90 92 100 133
164 79 74 69 67 68 71 89 73 88 69 66 56 53 58 50 81 89 74 68
74 66 69 77 82 101 80 65 74 71 42 73 55 43
CRL-D08B 54
143 138 106 103 92 117 122 118 174 175 98 132 130 95 77 54 76 91 114 112
140 87 73 64 72 60 78 81 71 92 70 75 58 35 66 46 84 89 70 73
63 80 66 66 87 94 89 69 71 69 46 77 46 48
CRL-D09A 96
108 109 126 99 133 121 125 186 116 165 143 130 92 119 85 67 58 98 87 127
116 115 55 111 96 125 126 137 152 155 123 95 161 147 126 164 162 131 160 150
112 102 113 93 120 92 105 86 114 100 79 57 87 111 63 88 97 106 119 124
138 148 142 99 129 139 134 115 132 152 129 84 77 81 76 99 78 102 143 98
146 139 134 148 158 121 143 119 117 117 112 166 181 117 136 145
CRL-D09B 96
119 105 120 108 124 125 100 111 114 137 156 127 131 140 109 71 85 83 120 126
97 118 58 108 97 137 116 141 140 145 137 100 163 138 116 177 150 123 156 140
118 109 114 98 116 96 103 92 115 108 69 63 87 111 60 84 101 109 111 128
135 151 133 107 131 131 130 131 128 161 128 86 79 79 71 105 73 107 135 102
147 137 129 143 169 118 145 108 121 125 113 144 152 149 134 157
CRL-D10A 124
120 90 117 135 116 88 117 117 86 99 80 88 86 90 86 72 52 45 47 72
65 88 73 75 49 60 75 135 128 151 131 124 121 85 111 122 102 158 148 133
125 151 118 105 124 104 114 91 113 89 109 110 84 71 84 118 67 87 83 115
109 146 134 178 141 125 140 155 158 142 128 162 129 85 82 94 81 122 83 116
156 127 178 172 154 137 182 137 123 111 123 129 120 144 146 108 126 151 138 166
136 176 167 156 111 66 71 86 115 96 96 98 142 152 114 165 134 149 156 134
133 157 154 132

CRL-D10B 124
123 88 114 126 127 85 116 112 89 104 74 89 84 101 78 74 42 43 54 69
78 90 58 76 43 64 86 140 128 137 136 139 115 94 114 111 118 147 140 111
142 151 107 113 128 109 107 101 121 84 108 114 78 70 88 122 70 80 100 105
125 130 147 170 144 120 140 149 161 128 150 159 123 91 85 92 79 111 97 125
132 135 182 154 146 148 163 139 139 114 126 114 114 148 158 108 123 157 157 164
124 164 172 152 103 71 76 76 121 104 82 100 147 145 125 152 148 139 162 141
130 154 136 128
CRL-D11A 332
76 93 92 91 81 84 66 71 97 74 51 60 72 91 67 39 49 67 65 85
80 88 61 57 63 42 52 66 76 70 69 52 44 48 38 27 43 55 75 64
68 77 61 60 38 38 51 71 73 86 67 61 69 60 58 42 52 77 69 77
89 48 52 47 38 65 55 61 66 60 64 68 65 68 51 56 72 59 57 70
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90 86 104 71 76 82 75 92 95 90 112 101
CRL-D11B 332
95 85 94 97 74 78 69 83 87 79 60 58 64 85 76 40 44 62 87 81
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81 85 76 111 108 94 87 86 81 93 81 91 67 93 71 97 89 107 98 84
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CRL-D12A 191
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85 100 81 77 56 40 55 66 67 84 92 63 66 82 75 83 66 70 67 88
69 65 85 69 70 48 51 76 94 92 105 102 86 52 42 66 85 104 138 109
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74 113 117 128 109 97 91 100 74 66 100

CRL-D12B 191
105 91 106 102 104 72 60 47 61 79 103 99 78 75 64 61 32 39 57 71
76 99 86 95 68 68 41 44 59 74 70 93 78 66 70 65 58 43 63 109
88 101 79 82 63 37 50 63 67 75 79 69 71 77 80 85 60 66 72 89
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108 108 65 44 70 87 110 102 125 105 103 99 80 92 84 149 123 104 110 110
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98 93 104 73 53 46 57 63 106 95 72 105 104 86 115 56 72 71 96 112
100 128 129 90 91 85 106 128 66 64 95 124 82 88 88 107 87 99 69 94
80 98 121 141 92 92 100 76 69 69 100
CRL-D13A 340
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44 54 56 45 50 66 67 76 76 59 58 71 69 83 93 84 97 93 71 56
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60 75 52 45 34 41 45 46 54 58 58 54 64 49 64 55 46 41 57 59
75 67 78 70 64 51 54 39 56 78 65 78 56 61 65 61 68 77 81 87
67 82 66 61 64 79 63 61 66 76 64 71 76 90 60 65 50 46 68 77
CRL-D13B 340
91 129 111 103 81 107 116 92 102 79 72 69 76 70 69 74 103 79 52 51
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47 63 83 62 82 62 58 56 45 66 78 66 83 81 51 58 60 57 48 63
67 61 46 66 70 58 45 63 78 79 67 69 76 85 72 62 79 55 48 85
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64 59 55 50 53 59 55 70 77 84 64 66 74 50 48 75 86 76 86 73
89 73 47 55 62 79 74 88 66 64 70 50 69 56 52 75 89 83 73 68
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68 67 83 73 65 50 58 30 60 73 62 78 65 60 57 60 75 78 75 80
74 77 69 59 63 82 66 61 50 88 60 76 81 77 71 53 46 43 66 95
CRL-D14A 226
130 135 105 80 60 84 128 149 134 137 131 125 114 80 111 103 111 120 110 142
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114 120 115 103 71 125 129 119 105 101 67 100 127 103 95 110 77 114 94 119
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