APPENDIX 17

SCIENTIFIC DATING

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Dendrochronological Analysis

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Timbers were excavated within Roman levels at the northern Lanes, in the same manner as at the southern Lanes (Groves 1993; 2010; McCarthy 2000). In total, 156 samples, representing 132 timbers, were submitted for dendrochronological analysis (Table 90), coming from Keays Lane (KLA) and Laws Lane (LAL).

During the late 1970s and early 1980s, 71 of the samples (five from KLA A; 16 from KLA B; 50 from LAL D) were examined by the tree-ring laboratory at Queen's University, Belfast, as part of research into the production of a continuous tree-ring chronology for the British Isles, in order to provide a base for the radiocarbon calibration curve (*eg* Brown *et al* 1986). The data from this analysis were made available, and have been incorporated here. The remaining 85 samples, including duplicates of a number of those examined in Belfast, were processed at Sheffield University. The analysis of duplicates was undertaken for the following reasons:

Trench	Samples	Timbers
KLA A	8	5
KLA B	23	19
KLA C	12	11
KLA D	10	10
KLA E	5	4
KLA F	7	7
KLA G	2	2
LAL B	1	1
LAL C	5	4
LAL D	83	69
Total	***156***	***132***

Table 90: Summary of the dendrochronological samples submitted from each trench

- to ensure that the archive records were as complete as possible;
- minimum ring requirements have been revised since the original Belfast analysis, thus some of the samples rejected in the 1980s are now considered suitable for analysis;
- to maximise the ring sequence lengths obtained from some timbers in order to ensure that they met the minimum requirements for full analysis;
- to resolve problems encountered with some samples when originally analysed at Belfast.

This study was undertaken with the aim of providing precise dates for the timbers, thereby providing additional independent dating evidence for the chronological development of the northern Lanes and facilitating links to stratigraphical sequences from adjacent sites.

In addition, a series of timbers and timber fragments from the northern Lanes stored at Shaddon Mill, Carlisle, since the 1980s, was assessed for dendrochronological potential, as these surviving timbers provided an opportunity, albeit limited, to add to or refine the extant dating evidence. The assessment led to only eight samples being selected for full analysis, based on a combination of archaeological prioritisation, previous failure to date, and the identification of potentially more suitable locations for sampling than was evident from the earlier work (Table 91). Unsurprisingly, given the length of time since the excavations, only one of these samples retained sapwood, though a further two retained the heartwood-sapwood transition and a further one retained a possible heartwood-sapwood transition. Five of these samples were successfully cross-matched and dated to the Roman period, whilst two samples remain undated (Fig 309).

Methodology

All samples were prepared and analysed using standard dendrochronological techniques (Baillie 1982; Hillam 1985). Any samples deemed unsuitable

Sample number	Rings	Sapwood	Date of measured sequence	Felling date
ETS B W1	89	?hs	undated	-
KLA B 186 W207	227	-	218 BC-AD 9	after AD 19
KLA D 502 W22	101	h/s	37 BC-AD 64	AD 74-119
KLA D W23	129	29 +1-2B	5 BC-AD 124	AD 125-6
KLA D 520 W63	125	-	131 BC-7 BC	after AD 4
KLA G 160 W34	164	-	undated	-
KLA G 165 W159	169	-	149 BC-AD 20	after AD 30

Key: hs = heartwood-sapwood transition present; B = bark edge present; +*n* = unmeasured rings

Table 91: Details of the eight extra samples

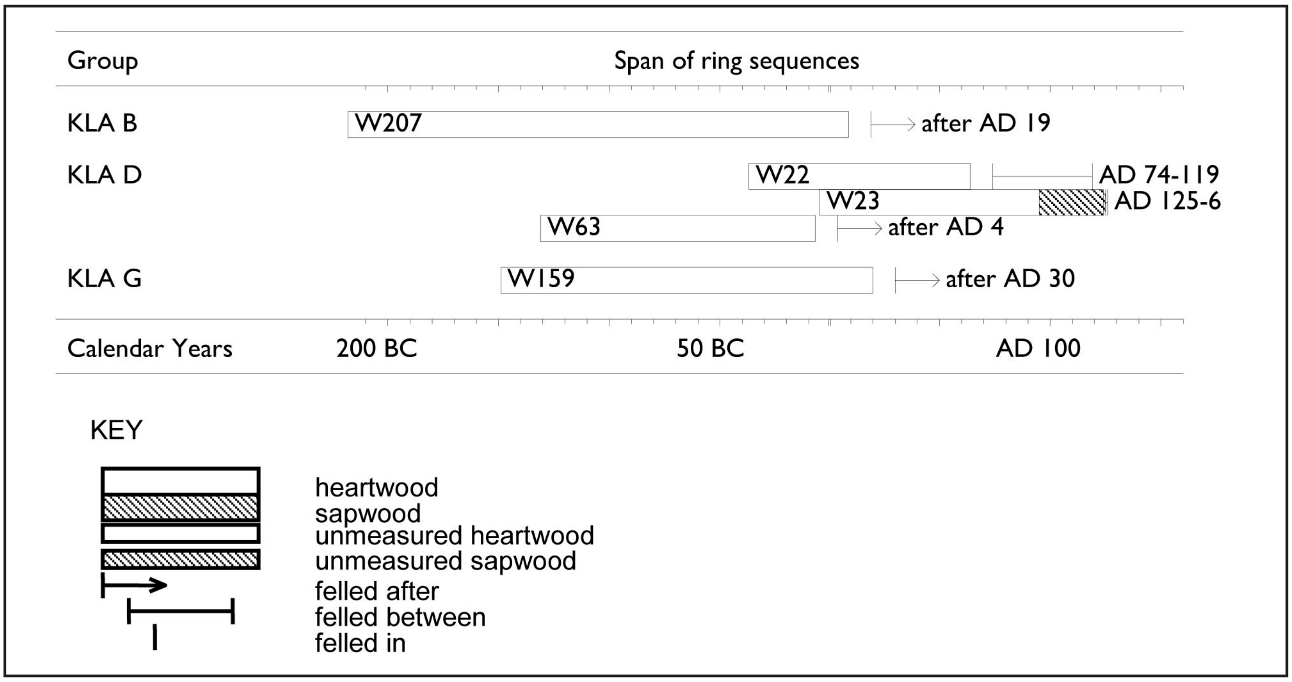


Figure 309: The scientific dating positions of the five dated Roman wood samples

for dating were rejected before measurement, but, where possible, a note was made of the number of rings and the estimated average ring width. Samples with unclear ring sequences, or fewer than 50 rings, are those usually regarded as unsuitable, because the ring sequence may not be unique (Hillam *et al* 1987). It should be noted that the limit applied at Belfast would have been fewer than 100 rings, as the original primary aim was the construction of a national chronology rather than the production of a specific dating framework for the northern Lanes. The one sample that was not of oak, identified via reference materials in the form of permanent slides, an identification key (Schweingruber 1990), and a computer database (*'Guess'* - see Wheeler *et al* 1986), was also rejected prior to measurement.

The growth rings of the samples selected for dating purposes were measured to accuracies of 0.01 mm (Sheffield) or 0.02 mm (Belfast), using a travelling stage attached to a computer system. The ring sequences were plotted as graphs on semi-logarithmic paper, in order to enable visual comparison between the ring sequences. This process is aided by the use of computerised cross-matching routines (Baillie and Pilcher 1973; Munro 1984), which measure the amount of correlation between two ring sequences. The Student's *t* test was then used as a significance test on the correlation coefficient. All *t* values quoted are identical to those produced by the original CROS program (Baillie and Pilcher 1973). Generally, a *t* value of 3.5 or over represents a match (Baillie 1982, 82-5), provided that the visual match between tree-ring graphs is acceptable, and that high *t* values are obtained at the same relative or absolute position with a range of independent chronologies.

Dating is usually achieved by cross-matching ring sequences within a phase or a discrete building, and combining the matching patterns to produce a master-curve for the site. This, and any unmatched ring sequences, are then tested against an extensive range of reference chronologies, in order to obtain calendar dates. A master-curve is used for scientific dating whenever possible, as it enhances the common climatic signal and reduces the background noise resulting from the local growth conditions of individual trees. An important additional element of tree-ring analysis is the identification of 'same-tree' timber groups during the cross-matching stage of the analysis. This is based on very high levels of similarity in both year-to-year variation and longer-term growth trends. Such information should ideally be used to support possible 'same-tree' groups identified from similarities in the patterns of knots/branches during detailed recording of timbers for technological and woodland characterisation studies.

The process produces precise calendrical dates for the rings seen in the surviving timber and do not, therefore, necessarily represent the felling date of the tree. The exact felling year can be determined, however, if bark or the bark edge is present on a sample. In addition, it is sometimes possible to determine the season in which the timber was felled, depending on the completeness of the outermost growth ring: a complete ring indicates that felling occurred during late summer/winter (*ie* during dormancy); an incomplete ring indicates felling in the late spring or early summer. In the absence of bark surface, the felling date is calculated using a sapwood estimate of 10-55 rings, this being the range of the 95% confidence limits for the number of sapwood rings on British oak trees over 30 years old (Hillam *et al* 1987). Where sapwood is absent, the addition of ten rings (the minimum number of sapwood rings expected) to the date of the last measured heartwood ring produces a probable *terminus post quem* for felling, *ie* the date after which the timber was felled. The actual felling date may be much later as, during timber conversion, a large number of outer rings could have been removed.

At this stage, it is necessary to incorporate other specialist evidence regarding the reuse of timbers and possible later repairs or modifications, as well as factors such as stockpiling or seasoning, in order to determine whether the dendrochronological dates actually reflect the construction date of the structure. The systematic seasoning of timber is thought to have been a fairly rare occurrence until relatively recent times, and evidence indicates that it was, in the past, normal practice to fell timber as required and use it whilst still green (*eg* Rackham 1990, 69). Construction which utilises primary, rather than reused, timber is therefore quite likely to have taken place shortly after felling. Thus, whilst the date obtained for the measured tree-ring sequence is precise, and has been achieved by a completely independent process, the interpretation of the dendrochronological dates can be refined by studying other archaeological and documentary evidence.

Results

Full details of all timbers and the results of the analysis are to be found in the site archive (Groves 1993, appendices 1 and 2). Summaries on a period-by-period basis are provided (*pp 775-80*; Fig 310), and information is also given, within each period, about timbers for which there is direct evidence of reuse, even if they remain undated. Of the 86 timbers (99 samples) measured, 55 timbers (62 samples) were successfully dated. In order to ascertain precise calendar dates, reference chronologies from throughout the British Isles were used, spanning the period 500 BC-AD 800. The most commonly used were those from elsewhere in Carlisle (the southern Lanes (Groves 1993; 2010), Annetwell Street (Groves 1990), and Castle Street (Groves 1991)); Ribchester (Hillam 2000); and Vindolanda (Hillam 1993)). Detailed information on the dating of all of the individual samples has not been presented, although some examples of intra-site cross-matching and of cross-dating of individual timbers with reference chronologies have been provided (Table 92). The dated individual sequences were combined to form a composite Roman chronology for all trenches in the northern Lanes (*below*). The ring-width data from this master-curve and from all individual samples and timbers are archived at the Sheffield Dendrochronology Laboratory.

Period 3

Two planks from the flooring of a pit (*1504*, pit *1505*; *Ch 2, p 27*; samples **663** and **664**) were dated. The outermost rings date to AD 52 and AD 50 respectively. The available date for **663** marks the sapwood boundary, and provides a felling-date range of AD 62-107, whilst **664** indicates a *terminus post quem* for felling of AD 60. Both timbers could be regarded as broadly contemporary, but the timber records for **663** show possible evidence for reuse, which might suggest otherwise.

Period 3-5

A single date was obtained for this period, from an isolated driven stake (LAL C *412*: sample **318**), which was dated to the period 94-42 BC. It had no trace of sapwood and thus simply provides a *terminus post quem* for felling of 32 BC.

Period 4A

Three offcuts (samples **141, 143, 146**), found in a spread of woodworking waste (KLA C *1348*) associated with the construction of Building ***1560*** (*Ch 2, p 29*; *Appendix 16*), were sampled. None retained any sapwood, and, assuming that they are contemporary, all were felled after AD 58. A fourth offcut (sample **287**; *405*; from the fill of ditch *430*; *Ch 2, p 28*), associated with

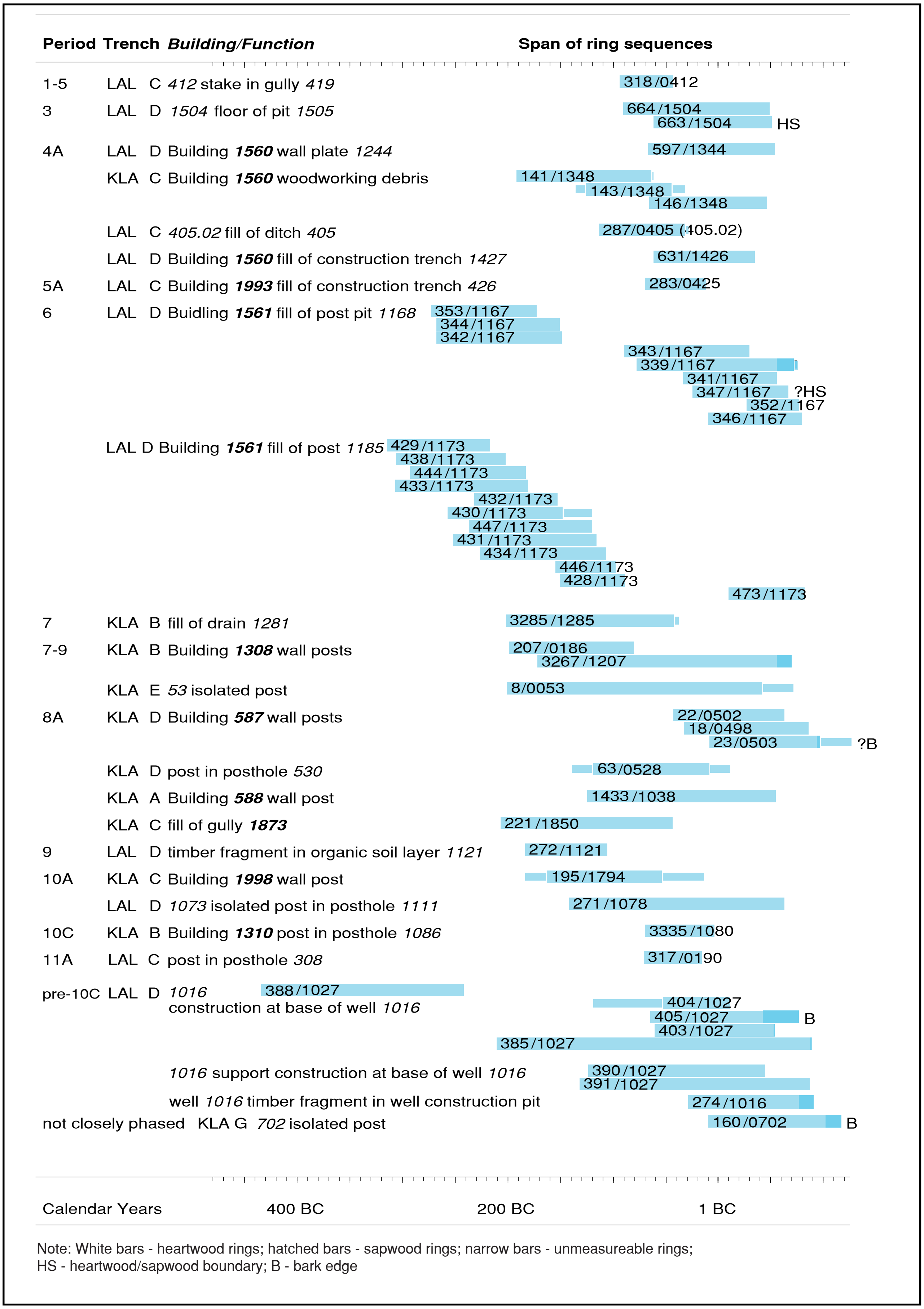


Figure 310: The relative positions of the dated ring sequences

Reference chronology sample nos	Lanes2	KLA A 1433	KLA B 3267	KLA C 146	KLA D 22	KLA G 160	LAL C 318	LAL D 271	LAL D 385	LAL D 388	LAL D 434	LAL D 663
Carlisle: Annetwell Street (Groves 1990)	17.63	6.49	6.66	5.83	6.36	4.99	9.39	6.50	7.22	\	4.77	5.84
Carlisle: Castle Street (Groves 1991)	10.69	5.56	3.48	4.82	5.58	3.74	8.82	5.98	4.55	3.02	-	5.06
Carlisle: southern Lanes (Groves 1993)	15.46	6.63	6.39	6.36	6.19	4.69	4.26	8.08	9.27	4.41	4.07	4.35
Alcester (D Brown *pers comm*)	4.49	4.21	-	-	-	-	-	-	-	\	-	-
Castleford (J Hillam *pers comm*)	5.16	-	3.72	-	3.11	-	-	3.02	-	\	3.96	-
Droitwich: Upwich (Groves and Hillam 1997)	7.91	3.02	-	-	3.19	3.67	-	3.42	4.34	-	3.50	-
London: Cheapside (Tyers 1992)	4.01	-	-	-	-	-	3.70	-	-	\	-	-
London: Guildhall Yard (Tyers 1994)	4.14	-	-	-	-	4.66	-	3.18	-	\	-	-
London: Regis House (Boswijk and Tyers 1996)	3.56	-	-	-	-	4.32	-	3.79	-	\	-	-
Nantwich (R R Laxton and C D Litton *pers comm*)	5.53	-	-	-	3.25	4.55	3.14	3.48	-	\	-	-
Papcastle (Hillam 1988)	9.25	5.62	-	5.39	5.22	4.02	4.53	7.39	5.69	\	-	-
Ribchester (Hillam 2000)	9.26	4.25	3.73	3.57	4.97	4.67	3.65	3.67	6.82	-	6.23	-
Vindolanda (Hillam 1993)	17.86	7.43	9.40	5.33	7.50	4.37	3.27	4.55	8.63	5.59	7.38	3.16
Walton-le-Dale (Groves 1987)	8.72	3.62	-	-	6.11	7.95	3.18	3.11	5.17	-	-	-
Wales: Caerleon (Hillam 1987)	3.68	4.33	-	-	4.08	3.98	\	3.02	-	\	\	-
Ireland: Dorsey Navan (Queens University Belfast nd)	6.53	\	-	\	\	\	\	-	-	4.85	3.41	\
Ireland: Keenagh (Queens University Belfast nd)	6.75	\	-	\	\	\	\	\	3.06	5.25	-	\
Germany: south (Becker 1981)	4.35	-	-	-	-	4.01	-	-	-	-	-	-
Germany: Trier (Hollstein 1980)	5.11	-	-	-	-	3.93	-	-	-	3.49	-	-

\ overlap less than 15 years; - *t* values less than 3.00; QUB Queen's University Belfast.

Table 92: Comparisons with reference chronologies for the Roman master sequence (Lanes2) and selected individual timbers

the construction of the same building, was dated to the period 114-31 BC. As no trace of sapwood remained, a *terminus post quem* for felling of 21 BC is suggested.

Sample **631**, an offcut found in a construction trench (*1427*) fill (*1426*) of Building ***1560*** (*Ch 2, p 31*), was dated to the period 62 BC-AD 36 and, in the absence of sapwood, a felling date of after AD 46 was obtained. In addition, a sill beam (sample **597**; *1484*; also from construction trench *1427*) from Building ***1560***, with an outermost heartwood ring dated to AD 55, gives a *terminus post quem* for felling of AD 65. No 'same-tree' links were identified amongst the dated samples from this period, so dendrochronology is unable to provide additional support for the relationship between the four contexts, all thought to be associated with Building ***1560***.

In addition, a further sample (post KLA G *165*; **W159**), also from Building ***1560***, was analysed. This newly analysed timber has a last ring date of AD 20 and is thus one of many timbers with last measured heartwood ring dates in the early part of the first century AD or earlier.

Period 5A
A single fragment (sample **283**), found loose in construction trench *426* (Structure ***1993***; *Ch 2, pp 43-4*), was dated. As there was no sapwood, it could only provide a felling date of after 1 BC.

Period 6
Nine timbers were dated from a post-pit (*1167*; pit *1168*) associated with Building ***1561*** (*Ch 3, p 52*). All appeared to be discarded offcuts, or fragments of thin planking, which had been incorporated into the post-pit fill. Three probable same-tree groups were found. Samples **342**, **344**, and **353** are likely to have been from a single tree, and all have outermost heartwood dates in the mid-second century BC. Samples **343** and **339** are from a different tree, and were felled after AD 73 but before AD 122. Samples **346** and **352** are from a third tree, and were both felled after AD 91. The remaining two timbers, **341** and **347**, were felled after AD 67 and during the period AD 78-123 respectively. It is possible that several felling phases are represented by the timbers from the post-pit, suggesting that these short planks either represent discards from a series of construction periods, or that some or all of the timbers have been reused.

Twelve timbers from a second post-pit (*1173*; pit *1185*) associated with Building ***1561*** (*Ch 3, pp 52-3*) were also dated. They, too, are discarded offcuts or fragments of thin planking, which were incorporated into the post-pit fill. Again, three same-tree groups were identified. Samples **429**, **433**, and **438**, from a single tree, have outermost heartwood rings dating to the late third- to early second century BC. Samples **431**, **434**, and **447**, from a second tree, have outermost heartwood rings dating to the late second century BC. Samples **428** and **446** appear to represent a third tree, and their sequences end in 88 BC and 97 BC respectively. Three of the remaining four timbers also have end-dates in the second century BC, implying that these timbers

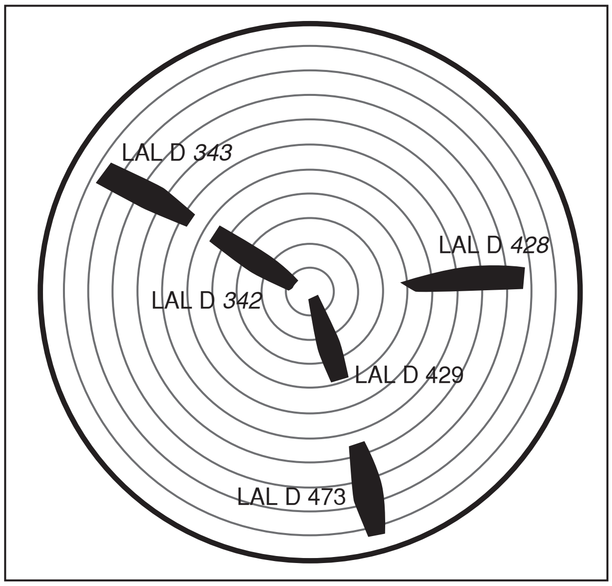


Figure 311: The possible method of conversion of dated planks from Period 6

are likely to have been derived from the inner part of a large trunk. The odd timber in this group is sample **473**, which has an outermost heartwood ring dating to AD 83 and was therefore felled after AD 93.

Comparisons made between the timbers from post-pits *1168* and *1185* show that samples **346** and **352** (from *1168*) are derived from the same tree as **473** (from *1185*). Combining results from the three samples indicates that the tree was felled after AD 93. The same-tree link between these two contexts supports other information which indicates that the two post-pits are contemporary, and associated with the same building (***1561***). It is also clear that, although 21 timbers have been dated from these two contexts, they may have been derived from relatively few trees. It is possible that some of the dated planks represent the inner section of a long-lived single trunk, whilst others may represent the outer part of the same trunk (Fig 311).

Period 7
Timber **3285** came from fill *1285* of drain *1289* (KLA B), in the east of the site, possibly part of a collapsed plank lining to the drain, and there is some evidence that this timber was reused. Its outermost measured heartwood ring dates to 42 BC but, as there were approximately five additional outer rings which were not measured, as they were crushed, its felling date is after 27 BC.

Period 7-9
Timber **207**, a wall post (*186*) from Building ***1308*** (*Ch 3, p 56*), was dated to the period 199-80 BC. It had no trace of sapwood, and thus has a *terminus post quem* for felling of 70 BC. A new sample has a last ring date of AD 9, and thus provides no significant improvement with respect to the identification of a felling date.

Timber **3267** was a post within the portico (posthole *1207*) of Building ***1308*** (*Ch 3*, *p 59*). It had retained 15 sapwood rings, the outermost of which dates to AD 71. The timber was, therefore, felled after AD 71 but probably before AD 112.

Timber **8**, an isolated post (*53*; in the south-east of the site), can be dated to the period 201 BC-AD 43. As there is no sapwood, a felling date of after AD 53 is produced. Other archaeological evidence suggests that this post may also have been associated with Building ***1308***, but the dendrochronological results can neither support nor deny this. Timber **205** (*181B*), a wall-post from Building ***1308*** (KLA B), although not dated, provides evidence of reuse for this period.

Period 8A

Sample **1433**, a wall post (*1038*) associated with Building ***588*** (*Ch 3*, *p 62*), shows clear evidence of reuse. No sapwood survived, so a *terminus post quem* for felling of AD 66 was obtained. Timber **221** was a fragment found loose in fill *1850* of gully/drain *1859* (KLA C). Its outermost measured heartwood ring dated to 43 BC, giving a felling date of after 33 BC.

Timbers **18**, **22**, and **23** (*498* (*496*), *502* (*573*), and *503* (*553*)) were all wall posts from Building ***587*** (*Ch 3*, *pp 62-3*, *66*). The dates of the outermost measured rings are AD 87, AD 64, and AD 98 respectively. Neither **18** nor **22** retained any sapwood, so the felling dates are after AD 97 and after AD 74. However, the measured ring-sequence from sample **23** includes four sapwood rings, the outermost of which dates to AD 98. It was estimated that there were about 30 more sapwood rings, not measured because they were crushed, to the probable bark edge. Thus, a felling date of *c* AD 128 is obtained for this timber. No same-tree links were identified between the three wall posts, so it is impossible to determine whether or not they are completely contemporary. A further post (sample **63**; *528*; posthole *530*), associated with Buildings ***587*** and ***588***, proved difficult to date, as the innermost *c* 40 rings (to the pith), and the outermost *c* 20 heartwood rings, were unmeasurable, being so narrow that the boundaries could not be reliably distinguished. The last measured ring dates to 8 BC, so a *terminus post quem* for felling of AD 23 is produced.

In addition, three further timbers from Building ***587*** were subsequently analysed, being duplicates of samples **22**, **23**, and **63**. The new sample from **22** has the same last ring date of AD 64, but this has now been positively identified as the heartwood-sapwood transition. It is thus now possible to assign this timber a felling date range of AD 74-119. The new element of sample **23** retains a last measurable sapwood ring dating to AD 124, and thus allows this timber to be assigned a felling date of AD 125-6. The new element of sample **63**, however, has a last ring date of 7 BC, and thus provides no significant improvement with respect to the identification of a felling date.

Although none of the dated wall posts (**18**, **22**, **23**) from Building ***587*** showed evidence for reuse, another, unanalysed, wall post from this building (sample **19**, from *499*; posthole *572*) showed clear signs. Further evidence for reuse within this period is provided by timber *509* (sample **47**), a wall post from Building ***588*** (KLA D; *Ch 4*). It contained a number of peg holes not associated with its apparent purpose within this building.

Period 9

Timber **272** (from layer LAL D *1121*) was described in the original record as an unworked piece of roundwood found loose in soil, but the sample received was from a heavily trimmed quartered trunk. Its outermost heartwood ring dates to 105 BC, producing a *terminus post quem* for felling of 95 BC.

Period 10A

The innermost 20 rings and outermost 40 heartwood rings of sample **195** (*1794*), a wall post from Building ***1998*** (*Ch 3*, *p 75*; KLA C), were unmeasurable, as the ring boundaries could not be reliably distinguished. The outermost measured heartwood ring dates to 53 BC, so a *terminus post quem* for felling of 3 BC was obtained. Sample **271** was an isolated post (*1078*) in the north-west of the site (LAL D). Its outermost heartwood ring dates to AD 64, suggesting that it was felled after AD 74.

Period pre-10C

Sample **274** was a plank from the infill of the construction pit behind the barrel lining of well *1016* (*Ch 3*, *p 75*). Its measured sequence included 15 sapwood rings, the outermost of which dates to AD 92, indicating that it was, therefore, felled after AD 92, and probably before AD 133.

Seven discarded structural timbers (samples **385**, **388**, **390-1**, **403-5**) were dated, which had been found loose in the infill (*1027*) of the construction pit for the same well. Samples **390** and **391** were lap-jointed planks, forming part of a box framework supporting the barrel lining at the base of the well shaft. Sample **388** dates to the period 434-241 BC, whilst the remaining six timbers cover the period 211 BC-AD 90. This suggests that plank **388** had a large number of outer heartwood rings missing, and therefore probably represents the inner part of a much larger trunk. Sample **405** was felled in AD 78/9; sample **403** was felled in the period AD 63-108; sample **385** has a felling-date range of AD 98-143; sample **404** had a *terminus post quem* for felling of AD 23. Thus, at least two different felling phases are suggested by these discarded timbers, perhaps implying that some timbers (*eg* **405**) could have been reused. Neither of the lap-jointed planks retained any sapwood, so it can only be said that these timbers were felled after AD 56 and after AD 98, respectively.

Two undated timbers samples (**389** and **392**) from infill *1027.03* (*Ch 3*, *p 77*) provide evidence for reuse. Both were lap-jointed planks associated with the box framework at the base of the well, and both had redundant mortices relating to their original use, rather than to their purpose within the well.

Period 10C

Sample **3335**, a loose fragment in posthole KLA B *1080*, associated with Building ***1310*** (*Ch 3*, *p 82*), was dated to the period 70-3 BC. No sapwood survived, so a *terminus post quem* for felling of AD 8 was obtained.

Period 11A

Sample **317** was a post thought to be part of a fence (*190*; in posthole *308*; *Ch 4*; *pp 92-3*). Its outermost heartwood ring dated to 15 BC, indicating that it was felled after 5 BC.

Material not closely phased

Sample **160** is from an isolated post (KLA G *702*) probably associated with a structure which post-dated Building ***1560*** (Period 4A). The ring sequence dated to the period 10 BC-AD 118. The outermost surface was recognised as that immediately under the bark, and it was noted that the spring vessels of AD 119 were partially formed. A felling date of late spring/early summer AD 119 is therefore produced for this timber.

Other material

In addition, a timber labelled LAL B *300*, **72**, was subject to further analysis. The new sample has been successfully dated, with a last ring date of AD 1175, which marks the heartwood-sapwood transition, and thus this timber has a felling date range of AD 1185-1230. The newly analysed sample and the previously analysed sample match, with a *t*-value of 15.68, demonstrating that these two samples do represent the same timber. This is important as it shows there has been no failure, in the intervening years, of the labelling of the timber at Shaddon Mill, and no failure in the labelling of the sample originally analysed. The dendrochronological analysis shows that this timber is derived from the same-tree as a group of three previously analysed samples (**11**, **32**, and **33**) from the southern part of the site (KLA G), a medieval well-lining, which has timbers felled in AD 1229. It is thus likely that, whilst the context from which it came is securely stratified as Roman (Period 8B), this was somehow wrongly labelled in the field.

Discussion

The results obtained from this analysis appear, at first glance, to have little archaeological value, certainly with respect to the provision of a precise dating framework for the excavations. However, if one looks beyond this, it becomes clear that the waterlogged structural timbers from Roman levels within the northern Lanes have produced a valuable body of data which, when combined with the medieval timbers yet to be reported on, will complete the dendrochronological analysis of the large group of material recovered from large-scale excavations carried out in Carlisle from the late 1970s to the early 1990s (Table 92). This already provides a valuable resource in understanding the development of the city, and will stand as a solid and detailed scientific dating framework for decades to come. The analysis has, in addition, posed a series of questions, only some of which have been answered thus far, and illustrated some of the problems inherent in understanding the taphonomic process for any waterlogged site, thus extending its significance beyond the city, and making an important contribution to understanding the manner in which timbers can be used to illustrate the formation and dating of wet sites in general. In addition, the level of preservation allows some aspects of contemporary woodland management and timber use within the growing Roman settlement to be illustrated with relative clarity.

A lack of precision

Prior to the completion of the dendrochronological analysis, the provisional dating for the site was based, as is usual, on stratigraphic information and dating provided by other elements of the material culture, from, for example, ceramics and coins. A comparison with the felling dates provided for each period can now be made (Table 93).

It is immediately apparent that the dendrochronological analysis did not provide the precision necessary either to confirm or challenge the mostly Hadrianic (AD 117-38) and Antonine (AD 138-92) dates suggested for the successive periods of occupation by other sources of dating. Many of the felling dates are simply *termini post quem*, falling in the first century BC or first century AD, and the remainder are, for the most part, felling-date ranges, usually spanning the late first and early second century AD, and usually based on the presence of sapwood on a single timber. On occasion, there is some closer correlation, with the felling-date range for Period 3 broadly supporting the late first-century date suggested from other sources, although it must be noted that it is based on a reused timber (sample **663**), and the felling date of AD 119 obtained from a single post (sample **160**), which is not closely phased, can just be placed in the early Hadrianic period. Interestingly, it was timbers from a pre-11B context which produced

Period	Provisional Dating	Tree-ring felling date
1-5	early Roman or conceivably earlier - poorly stratified features	after 32 BC
3	later first century	AD 62-107
4A	Hadrianic/early Antonine	after AD 65
5A	Hadrianic/early Antonine	after 1 BC
6	Hadrianic/early Antonine	AD 76-111 AD 78-?123 after AD 93
7B	Hadrianic/early Antonine	after *c* 27 BC
7-9A	Hadrianic/Antonine	AD 71-111 after *c* AD 83
8A	Antonine	*c* AD 128
9A	Antonine	after 95 BC
10A	Antonine	after AD 74
10C	late second/early third century	after AD 8
11A	early third century	after 5 BC
pre-11B	Antonine - stratigraphically isolated - ceramic evidence suggests contemporary with 8B-10A	AD 92-132 AD 78/9 AD 63-108 AD 98-143
Not closely phased	-	AD 119

Information is only given for those periods from which timbers have been dated.

Table 93: The provisional dating prior to dendrochronological analysis, and the combined felling dates obtained for each period

the earliest felling date (AD 78/9), even though they are associated with some of the later Roman activity.

One probable cause of this lack of precision lies in the general absence of surviving sapwood, with only 18 of the 132 timbers submitted retaining any trace of sapwood, and only ten of them providing a date. Although this echoes the situation seen in the timbers analysed from Castle Street (Groves 1991) and the southern Lanes (Groves 2010), it is in stark contrast to the situation at Annetwell Street (site ANN A), where, of the 460 Roman oak timbers submitted, just over 300 retained some sapwood, and approximately half of these had recognisable bark edge (Groves 1990). As a result, a very precise dating framework was obtained for that site, even though the occupation phases were often very close together in date (*ibid*). Thus it can be seen that the lack of sapwood prevents the provision of precise felling dates, without which dendrochronology cannot help differentiate between a series of occupation periods which cover a relatively short time-span.

Possible causes

There are several potential contributory factors which could result in an absence of sapwood. They include poor preservation, site-specific excavation techniques and sampling strategies, and reuse of timber. In this case, the latter is felt to be by far the most likely explanation. Poor *in situ* preservation conditions would certainly result in the loss of the much more vulnerable sapwood some time before the timber became a total loss. At nearby Annetwell Street (site ANN A), the preservation of environmental remains was clearly excellent for the early Roman periods (late first/very early second century) but conditions suitable for the preservation of environmental remains were not as good at either the southern or the northern Lanes (M McCarthy *pers comm*). In addition, conditions conducive to the preservation of sapwood can vary substantially across a single site. For instance, the large, multi-layered, lid of a pit excavated at Ribchester (Hillam 2000) was effectively unique on the site, as conditions were very good for sapwood preservation, when timbers from the rest of the site were much less well-preserved and sapwood was noticeably absent. At the same site, another indication that the presence or absence of sapwood was dependent on specific preservation conditions was that alder, a less robust timber, survived in the contexts where sapwood was preserved, but not in others (*ibid*).

Excavation techniques and sampling strategies have developed substantially since the late 1970s when, on occasion, the enthusiastic cleaning of waterlogged timbers by inexperienced or ill-informed workers had often resulted in the total removal of the sapwood.

In London, for example, the survival of sapwood on samples improved remarkably and suddenly in the early 1980s, when it became routine to have regular site visits from a dendrochronologist.

It is, perhaps, in terms of sampling that the situation has changed most appreciably. Some decades ago, it was usually the case that only a handful of timbers, those which the excavator thought would be most useful, would have been sampled. These would probably comprise one or two from key structures or contexts. Since then (within the constraints of time and finance), a total sampling policy has become standard, allowing the timbers first to be assessed by a dendrochronologist, and then, working in combination with the excavator and other specialists, they can be prioritised, in order to provide the most informative results possible. Indeed, total sampling is the only way in which the dating framework for a complex site with only short intervals between major phases can be resolved. To this end, a comparison between sampling and/or retention policies applied to structural timbers, at the Lanes and at Annetwell Street in 1981-4 (ANN A) and 1990 (ANN H), would perhaps be of interest.

Long-term storage is another factor in potential sapwood loss. Without carefully controlled conditions and monitoring, there is a possibility that sapwood will deteriorate to the point of disintegration. This is a problem which appears to have affected some of the timbers from the northern Lanes, and a small number of duplicate samples worked on at Sheffield had no trace of sapwood, whereas, according to the records made at Queen's University, they originally had sapwood surviving (for example sample **3267** from KLA B *1207*; *p 779*). This potential problem is now overcome by spot-dating a large number of timbers during the assessment stage, with the analysis expanded and completed at a later date. This has the added advantage of providing dating evidence prior to post-excavation analysis.

The situation at the northern Lanes

It seems, however, to be the case that none of these more general factors had a significant impact on sapwood survival at the northern Lanes. If just the sapwood, and possibly a few heartwood rings, had been lost due to any combination of these causes, previous studies would at least allow the assumption that the outermost measured heartwood rings would become progressively later for each period, even if differentiation between closely dated periods would still not be possible. This progression is not, however, apparent in the dated assemblage. Many of the timbers produced a ring sequence ending either in the first century BC, or the first half of the first century AD, and there are only two timbers which have rings spanning the start of the second century AD. This, taken in conjunction with the dating from other sources, seems to imply that many of the timbers are probably missing quite substantial numbers of heartwood rings, as well as sapwood. Some of this could be the result of timber conversion, in order to produce squared timbers for building, or it could be a strong indication of the later reuse of timbers from earlier structures. Secondary conversion of timbers, prior to their reuse, would be likely to result in further trimming of timbers and consequently the loss of either or both sapwood and heartwood rings.

Support for this hypothesis is provided both by information obtained during the excavation and from the dendrochronological analysis. Timbers with good evidence for reuse have been noted (*eg p 775*). The robbing of sill beams following the destruction of Building ***1560*** (the putative *mansio*) in Period 4B has also been noted (*Ch 2*). Evidence for the reuse of timbers seems scarce in the archaeological record, but it can be difficult to recognise unless redundant carpentry features are present, and it must be borne in mind that evidence for reuse in a few timbers can be of greater significance than it first appears, as it can be indicative of reuse on a much wider scale.

Methodological response to the lack of intra-site cross-matches

The poor quality of the intra-site cross-matching seen at the northern Lanes has led to a digression from the usual methodology of using intra-site cross-matching to create a site master-curve, which is then used for scientific dating purposes. Apart from the same-tree groups (*p 775*), little other intra-site cross-matching could be seen, either between periods (Table 94), or between trenches (Table 95). Thus, in this instance, it proved necessary to compare all individual ring sequences with reference chronologies in order to obtain calendar dates. This served to confirm some of the tentative matches identified previously, between samples which required additional replication before acceptance. Thus, the usual matching criteria of high *t* values at the same relative or absolute position within a range of independent sequences, and the support of satisfactory visual matching, have been achieved, but in a slightly non-standard way. This implies a disparity in woodland origin that would not normally be anticipated in a construction phase using freshly felled timber.

One explanation might be the use of imported timbers, but the quality of the cross-dating obtained for the site master chronology once again indicates the use of local woodlands. Reuse of timber would allow for the mixing of timber from different sources, as indeed would stockpiling. Stockpiling of green timbers seems unlikely, as one would still expect the outermost measured heartwood rings to become progressively later for each period. However, the storage of timbers

Samples	LAL D 388	LAL D 390	LAL D 391	LAL D 403	LAL D 404	LAL D 405
LAL D **385**	\	4.40	4.96	-	-	-
LAL D **388**		\	\	\	\	\
LAL D **390**			-	-	-	-
LAL D **391**				-	-	-
LAL D **403**					5.89	8.39
LAL D **404**						5.67

\ = overlap < 15 years; - = t-values less than 3.00.

Table 94: Matrix of t values obtained between the dated samples from timber framework 1027

Samples	KLA B 207	KLA B 3267	KLA B 3285	KLA B 3335	KLA C 141	KLA C 143	KLA C 146	KLA C 195	KLA C 221	KLA D 18	KLA D 22	KLA D 23	KLA D 63
KLA A **1433**	3.04	3.06	-	-	-	-	-	-	-	-	3.32	-	-
KLA B **207**		-	3.10	\	-	-	\	3.45	-	\	\	\	-
KLA B **3267**			-	-	-	**4.61**	**4.22**	-	-	-	**3.73**	-	3.07
KLA B **3285**				-	-	-	-	**4.06**	**4.51**	\	\	\	-
KLA B **3335**					\	**4.61**	-	-	-	-	-	\	**5.56**
KLA C **141**						**8.72**	\	**4.69**	-	\	\	\	-
KLA C **143**							**7.53**	-	-	\	\	\	**3.66**
KLA C **146**								\	-	-	3.07	-	3.35
KLA C **195**									-	\	\	\	-
KLA C **221**										\	\	\	-
KLA D **18**											5.60	4.50	4.71
KLA D **22**												**3.66**	-
KLA D **23**													\

\ = overlap < 15 years; - = t-values less than 3.00; t-values of over 3.5 are highlighted.

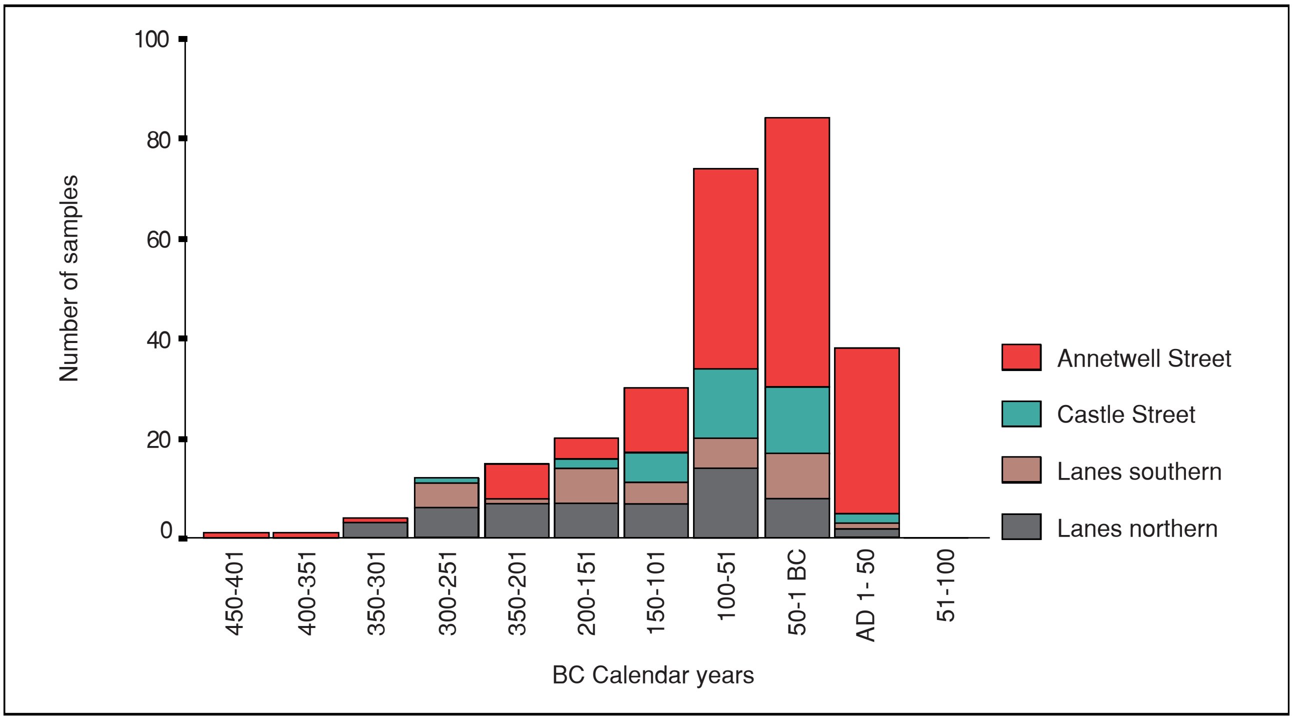
Table 95: Matrix of t values obtained between the dated samples from KLA A, KLA B, KLA C, and KLA D

salvaged from earlier buildings that had fallen into disuse or were to be replaced is a strong possibility, and would clearly allow for timber from a variety of woodland origins and different felling dates to be present in a single structure. Reuse of timber would also make sense particularly if, as implied by the Annetwell Street study (Groves 1990), the nearest woodlands had been severely depleted of suitable timber trees during the early days of Roman Carlisle.

Trees, woodland composition, and sources

The results thus seem to attest to the use of local timber rather than wood imported from afar. Consequently, the timber assemblage must, to a degree, reflect the locally available woodland. It must be noted that the dendrochronological analyses can never fully reconstruct a woodland, the surviving assemblage being only a very small percentage of the available woodland product. It does, however, add valuable information to a multi-disciplinary approach to landscape reconstruction.

There were quite clearly some very long-lived trees being used: sample **388** (from the construction trench for Period pre-10C well *1016* (*Ch 3*, *p 75*; *1027*)) has a first measured heartwood ring of 434 BC; **430/431/434** from the same feature have an earliest ring of 257 BC; samples **429/433/438** (from Period 6 post-pit *1185*) have an earliest ring of 315 BC; whilst samples **342/344/353** (from Period 6 post-pit *1168*) have an earliest ring of 273 BC. As the pith, or centre of the tree, was not present on any of these samples it must push their germination dates even earlier. Assuming that these trees were still living when the Roman occupation of Carlisle began in *c* AD 72/3, all would have been well over 350 years old when felled. They may only represent a handful of aged trees, but they certainly imply the presence of mature natural/semi-natural woodland in



Note: that for many of the sequences, this is an under-estimate of the birth-date of the parent trunk, as pith was frequently absent, and the height of the sample up the trunk is unknown

Figure 312: The start dates of the ring sequences from the northern and southern Lanes, Castle Street, and Annetwell Street

the surrounding area. These are, however, exceptional, as in general the longer-lived trees, both here and on other sites in Carlisle, appear to start growing in the third and early second centuries BC (Fig 312).

Interestingly, timbers derived from the oldest trees seem to appear more frequently in the later Roman periods at the Lanes. This has previously been noticed at Castle Street (Groves 1991) and Annetwell Street (ANNA), although the latter is unusual, as it also seems to have large quantities of very young/short-lived trees present in its second major phase of construction (period 5; Groves 1990). It should, however, be borne in mind that such differences between the sites may simply be a reflection of differing sampling and retention policies.

Nonetheless, the results from the Lanes could indicate that the area under exploitation for the procurement of wood had been extended to include areas of more mature woodland, perhaps growing further away from the settlement, or, alternatively, that the older/larger timbers were more frequently reused, as their size would have increased their potential for reuse. The lack of dated timbers coming from trees growing in the second century AD (*p 785*) could be a consequence of the over-exploitation of local woodland resources in the initial stages of the development of Roman Carlisle, which subsequently resulted in the need to reuse many of the larger structural timbers. It is also possible that, in the later periods, much younger trees were being used, as seems to have been the case at Annetwell Street. In this case, their age and size would have made them far less likely to be dated by dendrochronology and they would not have been included in the dendrochronological assemblage.

The large body of tree-ring data that is now available for Roman Carlisle allows for the valid comparison of utilisation patterns and the longevity of trees, with other areas, such as Roman London (Tyers 1992; 1994; Boswijk and Tyers 1996). The late Iron Age woodland around Carlisle clearly contained a higher percentage of very mature trees (around 300 years old when felled) than the woodlands around London, which produced only a handful of timbers with ring sequences extending back as far as 200 BC. Approximately 20% of the *c* 300 dated samples from Roman structures in Carlisle extend back beyond 200 BC, compared with less than 1% of over 600 dated samples from Roman structures in London. Another notable point is that the average width of all individual dated rings (31,779 rings) from Roman contexts in Carlisle is 1.17 mm, compared with 1.73 mm for the London data (67,194 rings). (Over 99% of all measured samples from historic and prehistoric periods in England have average ring widths of between 0.5 mm and 4.0 mm). Thus the 0.56 mm difference between Carlisle and London appears significant, indicating that the trees in north-west England were growing at a slower rate than those in the south-east of England, perhaps as a result of climatic differences.

Dendrochronological implications

Fifty-five (64%) of the 86 timbers measured were dated. This is a higher percentage than any of the other Carlisle sites which have produced Roman timbers (*eg* Annetwell Street 51%; Castle Street 51%; southern Lanes 52%). The reasons for the increase are unclear, but whenever ring-sequence lengths are analysed at this and other large Carlisle sites, it can be seen that, at the northern Lanes, the highest percentage of samples fall into the 100-49 range, whilst on all other sites, the majority fall into the 50-99 bracket (Fig 313). In broad terms, an increase in sequence length increases the likelihood of obtaining a date, so these slightly longer ring sequences are more suited to dating. It is possible that this is a reflection of retention policies during excavation, and of subsequent sampling strategies, meaning that only the largest timbers, with most rings, were retained for dendrochronological purposes.

It was initially thought that this high success rate might be due to the more extensive and well-replicated reference sequences available at the start of the study, than was the case for earlier studies in the region. It has, however, been possible to exclude this bias, as, having rechecked the undated samples from all previous Carlisle sites, it proved impossible to date more than a few, and it seems unlikely that the strength of the regional chronology does not appear to have been a significant factor.

Prior to this analysis, the composite Carlisle reference chronology spanned a range from 372 BC to AD 103. The data from this study have extended the Carlisle tree-ring reference sequences considerably, back into the fifth century BC and further forward into the second century AD (434 BC-AD 118), although even now, only two samples (**160** (KLA G *702*; Castle Street 289) from over 900 timbers from Carlisle submitted for analysis have rings dated to the second century AD. A further two timbers (**23**; posthole KLA D *553*, Period 8A Building ***587***; Castle Street 341) had unmeasurable rings extending into the early part of the second century, but the representation of second-century timbers remains low. This is comparable with site reference chronologies from other Roman sites in north-west England. Those from Papcastle (Hillam 1988), Ribchester (Hillam 2000), Vindolanda (Hillam 1993), and Walton-le-Dale (Groves 1987) end in AD 106, AD 91, AD 103, and AD 119 respectively, even though at all these sites some of the timbers were recovered from early-mid-second-century features or, in the case of Walton-le-Dale, third-century features. Indeed, with the exception of a single sample from Glebe Farm, Barton-upon-Humber (J Hillam *pers comm*), no site outside south-east England has provided datable timbers for the mid-second century AD onwards.

There also remains a gap in the English tree-ring chronologies for the fourth century AD, which has resulted in the pre-AD 400 chronologies being dated using Irish and German reference sequences. This gap is covered by only one site on mainland Britain. The chronology derived from timbers analysed for Whithorn (Crone 1997) in south-west Scotland, a region beyond the immediate effects of the Roman influence, spans

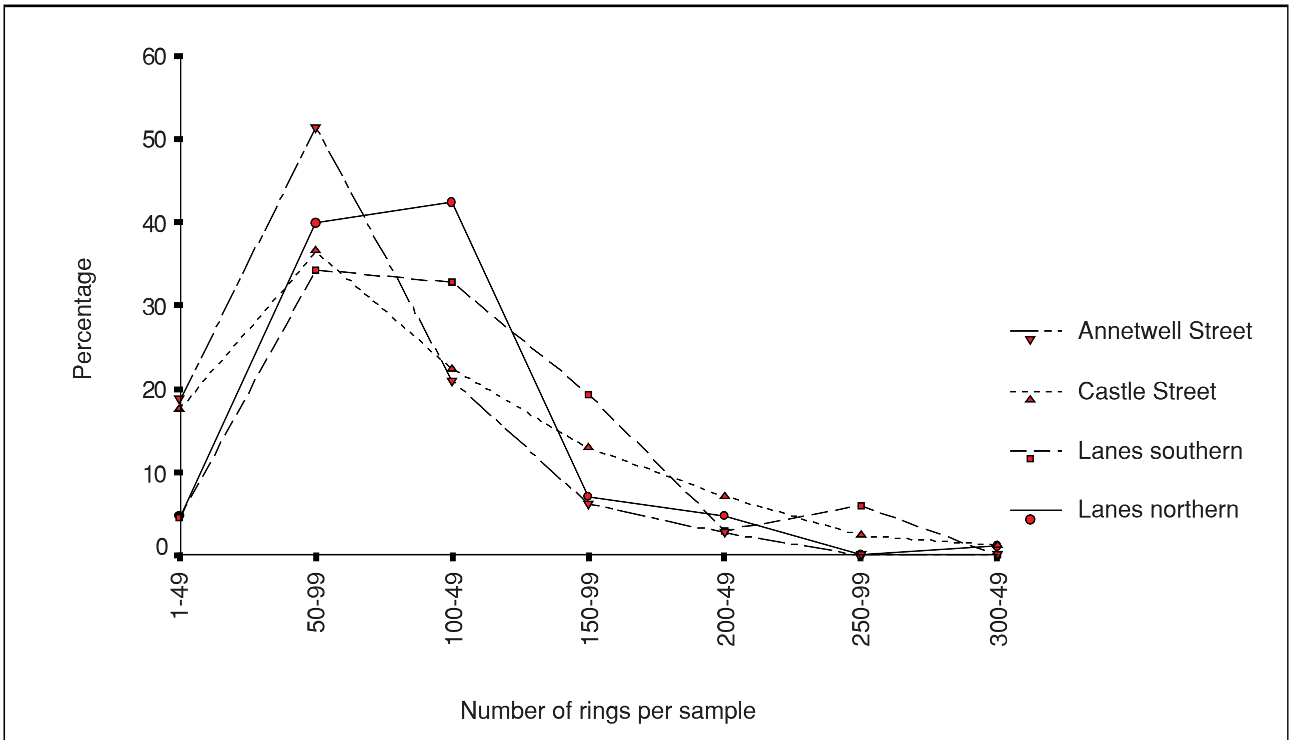


Figure 313: The total ring-sequence length from the northern and southern Lanes, Castle Street, and Annetwell Street

the period AD 278-752. This could well have interesting implications for the impact on the woodland landscape during and after the Roman occupation.

In addition to extending the chronologies, this study has also consolidated the data available from earlier sites for the second to the fourth centuries BC. The replication of this part of the composite chronology for Carlisle has significantly improved, and may now make an important contribution to the dating of sites further away from the area. This remains particularly important because chronologies which span the first few centuries BC and the first century AD are concentrated in north-west and south-east England, with relatively little data available from between the two zones.

Radiocarbon Dating and Chronological Modelling

Alex Bayliss, Christopher Bronk Ramsey, Gordon Cook, and John Zant

In total, ten radiocarbon ages have been obtained on eight samples of articulating animal bone from the northern Lanes, that contained sufficient collagen for accurate radiocarbon dating. The protein preservation in five further samples from this site (Period 11D-12: KLA A *612*, sample 1; KLA B *289*, sample 5; KLA B *732*, sample 9; and KLA C *886*, sample 10; Period 11E: KLA A *628*, sample 2) was not suitable for dating and so these samples failed in laboratory processing.

Five samples were processed and dated by Accelerator Mass Spectrometry (AMS) at the Scottish Universities Environmental Research Centre (SUERC) in East Kilbride, using methods described by Stenhouse and Baxter (1983), Vandeputte *et al* (1996), Slota *et al* (1987), and Xu *et al* (2004). Four samples were prepared at the Oxford Radiocarbon Accelerator Unit (OxA) using methods outlined by Brock *et al* (2010) and Bronk Ramsey *et al* (2004a), and dated by AMS, as described by Bronk Ramsey *et al* (2004b).

Both laboratories maintain continual programmes of quality-assurance procedures, in addition to participating in international inter-comparisons (Scott *et al* 2010a; 2010b). These tests indicate no significant offsets and demonstrate the validity of the precision quoted. In addition, the pairs of replicate measurements made on Period 11D-12 KLA B *285*, sample 12, and KLA B *706*, sample 7, are both statistically consistent (T′=1.7 and 0.9 respectively; T′(5%)=3.8; ν=1; Ward and Wilson 1978).

The results (Table 96) are conventional radiocarbon ages (Stuiver and Polach 1977), quoted according to the Trondheim convention (Stuiver and Kra 1986). The calibrated date ranges were calculated by the maximum intercept method (Stuiver and Reimer 1986), using the program OxCal v.4.1 (Bronk Ramsey 1995; 1998; 2001; 2009) and the INTCAL09 dataset (Reimer *et al* 2009). They have been rounded outwards to the nearest ten years, when the measurement error is ±25 BP or greater, and to five years when it is less. The calibration of these results by the probability method has also been calculated (Fig 314; Stuiver and Reimer 1993).

Laboratory Number	Sample reference	Context	Radiocarbon Age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Calibrated date range (95% confidence)
SUERC-36665	KLA B *706*, Sample 13	Articulating cattle calcaneum and astragalus from an accumulation of mixed 'dark earth', within a later Roman stone building (***2000***). It was sealed by a layer of 'dark earth' containing little rubble or other debris (see KLA B *704*, Sample 6).	1850±35	-22.1	7.2	3.3	cal AD 70–250
OxA-25344	KLA B *285*, Sample 12	Articulating cattle first and second phalanges from the upper part of an accumulation of 'dark earth', which formed just outside the main entrance to the later Roman building (***2000***).	1769±26	-21.59	5.5	3.2	cal AD 235–380 (1746±19 BP; T′=1.7; T′(5%)=3.8; ν=3.8)
OxA-25345			1720±27	-21.55	5.5	3.3	
OxA-24960	KLA A *680*, Sample 3	Articulating cattle calcaneum and astragalus from the single fill of a pit (KLA A *715*), located just outside the north-east corner of the later Roman stone building (***2000***).	1902±28	-21.32	7.7	3.2	cal AD 30–140

Table 96: Radiocarbon dates and stable isotope measurements

Laboratory Number	Sample reference	Context	Radiocarbon Age (BP)	δ ^{13}C (‰)	δ ^{15}N (‰)	C:N	Calibrated date range (95% confidence)
OxA-24961	KLA B *706*, Sample 7	Articulating cattle calcaneum and astragalus from an accumulation of 'dark earth', in the later Roman stone building (***2000***). It was sealed by a layer of 'dark earth' containing little rubble or other debris (KLA B *704*, Sample 6).	1919±28	-21.68	7.7	3.2	cal AD 55–135
SUERC-38325			1880±30	-21.8	7.5	3.4	(1901±21 BP; T′=0.9; T′(5%)=3.8; ν=3.8)
OxA-24962	KLA C *1051*, Sample 11	Articulating cattle calcaneum and astragalus from a rubble fill of a fire-pit for a hypocaust system within the later Roman stone building (***2000***).	1873±28	-21.49	6.2	3.1	cal AD 60–230
SUERC-35246	KLA B *721*, Sample 8	Unfused cattle diaphysis and epiphysis of distal femur from an accumulation of 'dark earth', within the later Roman stone building (***2000***).	1845±30	-22.1	7.2	3.5	cal AD 80-250
SUERC-35245	KLA B *704*, Sample 6	Articulating cattle first, second, and third phlanges from an accumulation of 'dark earth', within the later Roman stone building (***2000***). The deposit itself overlay a similar layer of 'dark earth', containing mixed sandstone rubble and other debris (see KLA B *706*, Sample 7).	1860±30	-22.1	6.6	3.3	cal AD 70-240
SUERC-35244	KLA B *285*, Sample 4	Articulating pig calcaneum and astragalus from a deposit comprising the uppermost part of an accumulation of 'dark earth', just outside the main entrance of the late Roman stone building (***2000***).	1845±30	-21.8	9.0	3.2	cal AD 80-250

Table 96: Radiocarbon dates and stable isotope measurements (cont'd)

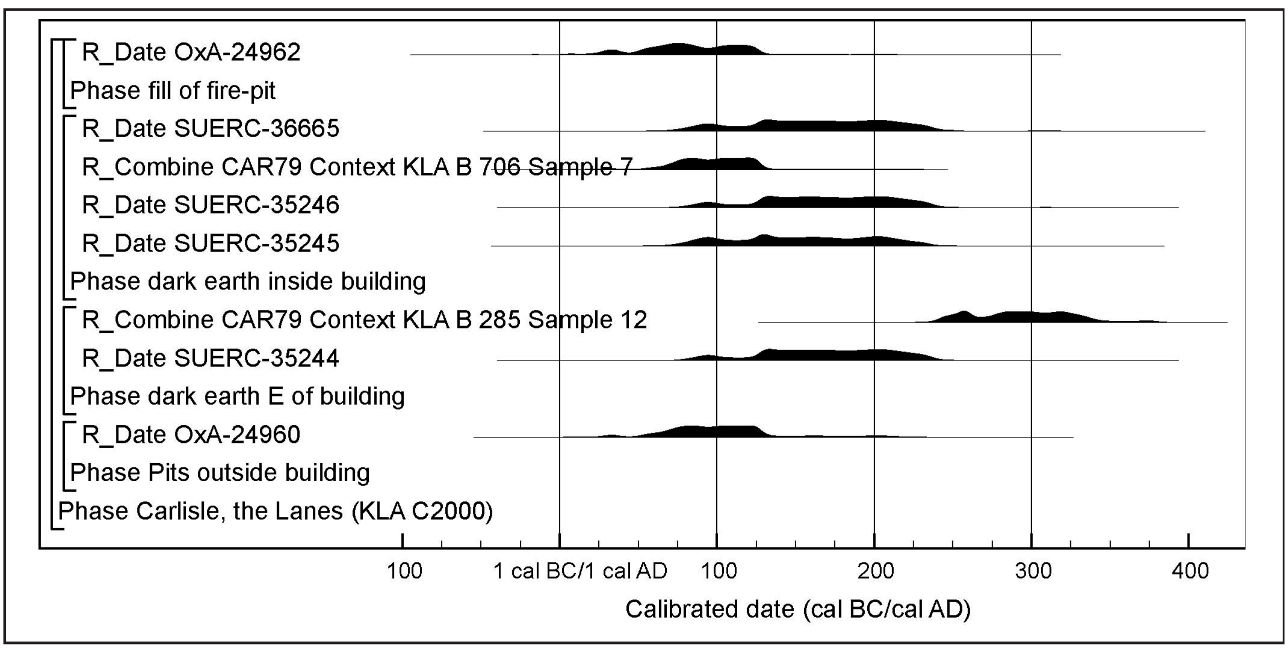


Figure 314: Calibration of the radiocarbon results using the probability method

A Bayesian chronological model, that includes these eight radiocarbon dates, the dated coins from Periods 11 and 12, and the phased site sequence from the northern Lanes, has very poor overall agreement (Amodel: 0). Two coins, a radiate copy from gravel surface *830* in Period 11A (**A119**; *Appendix 3*; *Ch 4, p 93*), and a coin of Constantius II from make-up *135* (KLA D) in Period 11B (**A201**; *Appendix 3*), seem to be intrusive in the contexts from which they were recovered, and the copper-alloy denarius of Trajan from 'dark soil' *289*, east of Building ***2000***, in Period 11D-12 (**A34**; *Appendix 3*; *Ch 4, p 130*) is clearly residual. Interpreting these coins in this way produces much better overall agreement between the phasing sequence and the dating evidence, although one of the articulating bone samples from the demolition debris from Building ***2000*** (KLA B *706*, sample 7) has poor individual agreement (A: 4) and reduces the overall agreement of the model undesirably (Amodel: 50; model not illustrated). This sample is clearly earlier than its stratigraphic position would suggest.

As two statistically consistent radiocarbon measurements from different laboratories are

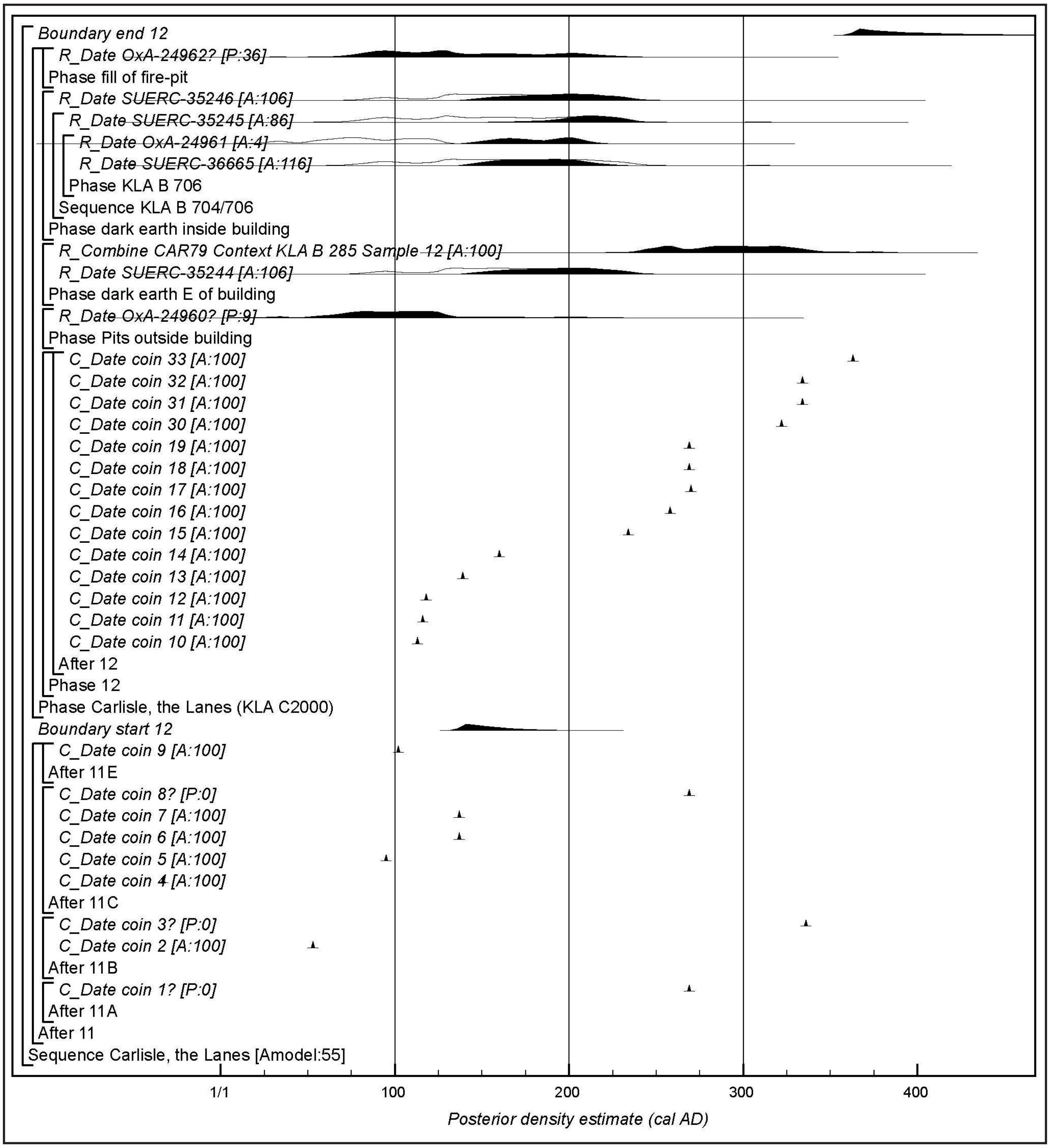


Figure 315: Probability distributions of dates from Period 11 and 12 deposits

available for it (OxA-24961 and SUERC-38325), there must be an issue with the archaeological provenance of the dated material. It seems unlikely that an articulating group of animal bones would be residual, although the reworking of an articulated bone group into a subsequent deposit is not impossible. Similarly, it is possible that the context was not clearly defined on excavation and the sample actually derived from an underlying deposit.

Whatever the cause of this anomaly, when, sample 7 from the demolition of Building ***2000*** (KLA B *706*) is excluded from the model, this has good overall agreement (Amodel: 91; Fig 315). This model suggests that the dark soil began to accumulate over Building ***2000*** (*Ch 4*, *p 127*) in cal AD 135-95 (95% probability; start 11D-12), probably in cal AD 135-65 (68% probability). On the basis of coin evidence, it may have continued to accumulate at least until the middle decades of the fourth century AD.