COPPERGATE DENDROCHRONOLOGY

I. TREE-RING ANALYSIS OF TIMBERS FROM THE SUNKEN BUILDINGS

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Abstract

The results from the first series of analyses of the Coppergate timbers are presented. 104 timbers from the 9th to 11th century sunken building phase at 16-22 Coppergate, York, were sampled and examined during 1977-1985. Timbers from eight out of the nine structures were dated, although there were difficulties, both in the crossdating and in the interpretation of the tree-ring dates. Details of the dating, and of the types of timber used in the structures, are discussed.

Contents

Coppergate Dendrochronology - An Introduction

Tree-ring analysis of the Coppergate oak timbers was carried out at the Sheffield Dendrochronology Laboratory from 1977 to 1985. Most of the 383 samples were from the excavations at 16-22 Coppergate (Hall 1984), but twenty of the timbers were sampled during the watching brief on the Coppergate Development site. The analysis and dating of the Coppergate timbers has presented many problems, since the site is the most complex urban rescue excavation in Britain for which dendrochronology has been used. The tree-ring results will be presented at some length because, as well as providing a dating framework and other information for the site, much has been learnt about the use of dendrochronology for such complex sites which will be useful for future large-scale excavations.

The timbers were excavated over several years (1976-82). Tree-ring samples were taken at intervals during this period by members of the York Archaeological Trust under the Directorship of Richard Hall, although some were not sampled until during the post-excavation work, and a few were left until they had been conserved. This has made the tree-ring work difficult since there has frequently been insufficient information about the timbers. Much of the post-excavation work for the 9th to 11th century sunken building phase is now complete, and all the available information has been sent to Sheffield. A report on the tree-ring work for this phase follows. Other reports in the Coppergate series will be:

II) Wattle phase timbers - a report on the 'Viking' timbers from the post-and-wattle phase which preceded the post-and-plank sunken building phase (Periods 3-5a).

III) Coppergate Development site - although this includes timbers from sunken buildings, the results will be presented in a separate report when more information becomes available.

IV) The medieval timbers (Period 6).

V) A general review of Coppergate dendrochronology. This will cover the following aspects:

a) Methods and principles

b) Problems associated with Coppergate

c) Dating

d) Interpretation of the tree-ring dates; sapwood

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f) Timber trade: re-use of timber, stockpiling, transport of timber

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Coppergate Dendrochronology

I. Tree-ring analysis of timbers from the sunken buildings (Period 5b)

In the late 10th century, the wicker buildings which occupied the four tenements at 16-22 Coppergate in York were replaced by buildings of substantial oak planks and posts which were sunk below the ground by as much as 1.5m. Two of the tenements had two ranks of buildings, one at the street frontage and the other a few metres behind. The latter were occupied by workshops whilst those along the street served as living and storage areas. A single structure was built on a third tenement and, on the fourth, a two-roomed building (Structure 3) replaced separate structures (Hall 1984 67). During the later stages of Period 5b, a new building was erected at the river end of one of the tenements. This may have been a warehouse for the storage of materials produced by the various workshops. It was finally replaced by a building known as the 'Bakery'; timbers from this structure will be discussed in the report on the medieval timbers.

Timbers from, or associated with, nine structures have been examined. (The definite labelling of the structures and tenements came too late for inclusion in this report, but are listed as an Appendix.) The primary aim of the study was to provide a date for the construction of the various buildings, and the length of time for which they were occupied. Details of the timbers were also collected in the hope that they would provide some information about woodlands and the use of timber in Viking York. Five of the structures were from the phase of building which immediately succeeded the wicker phase: Structures 5 and 7 on the street frontage; and the workshops, Structure 1, Buildings 2 and 3 (Fig 1). Other timbers were from Structures 2 and 3, which

replaced Buildings 3 and 2 respectively. Finally timbers from the Warehouse, and from the later Structure 6, were also sampled. The timbers from each structure are described separately (Table 1), along with any tree-ring dates. The ring width data are available on request from the Sheffield Dendrochronology Laboratory.

Tree-ring dating

Progress on the Coppergate timbers was slow and difficult, and for a time it was thought that no reliable dating would be obtained. Possible reasons for this will be discussed elsewhere, as will a more detailed account of the methodology, although basic introductions to the subject can be found in Baillie (1982) and Eckstein et al (1984). It is impossible to give a step-by-step account of progress, nor does space allow the reproduction of the evidence for the dating of each timber. This again will be left until a later report. In brief, relative dating was achieved by crossmatching the ring pattern from one timber with those from at least two others. This was done by visual comparison of the tree-ring graphs, and by the use of a computer program (Baillie & Pilcher 1973). Independent master curves were constructed from two groups of matching ring sequences, and these were tested against dated reference chronologies. Consistent results were obtained for the two masters when they were compared with chronologies from London (Hillam 1981), Dublin (Baillie 1977), southern England (Fletcher 1977; Ref 6), west Germany (Hollstein (1980) and Schleswig-Holstein (Eckstein pers comm). The dated Coppergate master curves were then used to date further ring sequences (Hillam 1986). The Lincoln Cathedral chronology, AD 882-1184 (Laxton et al 1982), which became available in 1983, has also proved valuable in dating many of the Coppergate timbers.

Sapwood and interpretation of tree-ring dates

Once the timbers were dated, felling dates were estimated by allowing for missing sapwood rings. The number of oak sapwood rings is relatively constant at about 10-50 rings. Baillie's figure of 32±9 (Baillie 1982), where ±9 is one standard deviation from the mean, was used during the initial examination of the Coppergate timbers. The figure agrees well with that given by Hughes et al (1981) in their review paper on oak sapwood estimates, and it seems to apply to many timbers examined at Sheffield. However the value 32±9 suggests that the data has a normal distribution, which is not true (Hillam et al 1986), and it is often misinterpreted. This factor, plus the examination of new data from various regions of north-west Europe (Hillam et al 1986), has led me to adopt a sapwood estimate of 10-50 rings. This is a working model which should apply to 95% of samples (ie it represents a two standard deviation range). In fact, there is evidence that the number of sapwood rings increases from east to west across north-west Europe, and that trees older than 100 years have more sapwood than those younger than 100. However this variation has not yet been quantified: after more data has been collected and studied statistically, it may be possible to refine the sapwood estimate to take into account these two factors. (It may however prove impossible to apply, since the age and location of archaeological timbers is rarely known.)

That sapwood varies from tree to tree can be seen from the examination of those Coppergate timbers which retained all their sapwood, ie they were complete out to the bark edge (Fig 2). The results are consistent with the sapwood estimate of 10-50 rings, and they also show the impossibility of predicting precise

felling dates in the absence of some or all of the sapwood rings. Where no sapwood remains, the terminus post quem is given by adding 10 rings to the date of the last measured heartwood ring. Such samples are obviously not as useful as those which retain sapwood (Eckstein et al 1984).

The number of sapwood rings also varies within trees. There are more sapwood rings towards the crown of a tree than there are near the base of the trunk (Hughes et al 1981), and the number varies around the circumference. The transition from heartwood to sapwood does not follow a single ring; there may be more at one side than at the other. Timber 8905 from the top of Building 2, for example, has 16 sapwood rings at one side and 34 at the other.

Results

a) Structure 1 - Area 2 workshop

The eleven samples from this structure consist of five planks, two (8221, 8362) from the walls, and three from the backfill (8065, 8066, 8105); sill beams from the west (8849) and east (8379) walls; and four posts (8234, 8354, 8387, 8955). The two timbers from the backfill may not be part of the structure, but they could give some indication of when the building went out of use. There is also some uncertainty about the association of timbers 8221 and 8955 with the structure (R Hall pers comm).

The timbers had been split and hewn in a variety of ways: 8955 is a roughly squared trunk; 8387 a tangentially-cut plank; 8065, 8066, 8105 are radially split planks and 8234 is a halved trunk (Table 1a). The diameters of the trees used for this structure were also variable: 8849, for example, was split

from a tree with a diameter twice that of the tree used for 8955. Some of the timbers (eg 8354) had had their sapwood removed, but it was preserved on others. 8387 retained its full complement of sapwood rings, and had been felled in winter or early spring since its outer ring was completely formed.

It is impossible to calculate the exact age of the trees since the timbers were not complete segments of the trunk: they did not have both pith and bark edge. Some timbers (eg 8221, 8955) were from trees aged about 70-100 years when felled, but 8849 must have been produced from a tree of more than 200 years of age.

Some of the ring sequences crossmatched better than others: 8379, 8387 and 8955 formed a group, as did 8234, 8354 and 8849; 8065 and 8066 matched each other, but less well with the other Structure 1 ring patterns. 8105 and 8362 did not match with any of the other sequences: 8362 because no similarity could be found between its ring pattern and any other, and 8105 because its short curve was not unique. With the exception of 8105 and 8362, calender dates were assigned to all the timbers. They were not all felled at the same time (Table 2). One of the timbers (8387) was felled in late AD 972 or early 973. Other timbers (8379, 8955, 8234, 8354) may be contemporary, and were probably felled for the construction of the workshop. It is not likely that the timber was seasoned since wood was used green until very recently, unless it was to be used for panelling or furniture (eg Rackham 1976 76). The possibility of some form of stockpiling or re-use must be considered and this will be discussed below, but the simplest explanation is that the timbers were felled in AD 972/3, and used for construction soon after.

8849 was felled during the period 976-1016, and probably represents a late repair to the structure (R Hall pers comm). 8221 also seems to be a repair, since it was felled 994-1034, whilst the timbers in the backfill (8065, 8066) were felled some time after 1001 (Fig 3).

b) Structure 2 - Area 4 workshop

Eleven structural timbers were examined, plus four which may have been structural (8071, 8075 from the backfill; and timber fragments 8316, 8470). Of the structural timbers, some were uprights and others were planks (8213, 8215, 8293). The planks were split radially from trees over 200 years old, whilst the posts were whole, halved or quartered trunks of trees which were probably 100-150 years old when felled. The diameter of the tree trunks must have been variable, with the radial planks coming from trees of larger diameter than the posts.

The plank ring patterns were very similar, and matched well with many of the other 10th century sequences from Coppergate. The post ring patterns, on the other hand, did not match either with each other or with any other Coppergate curve. 8214 was rejected because it had only 30 rings, whilst 8075 and 8275 had very complacent patterns of under 50 rings, but the other timbers seemed suitable for tree-ring dating. 8071, from the backfill, and 8316, a post fragment found on the west wall sill beam, were dated, as were the planks. The planks and 8316 appear to be contemporary, and were felled after AD 951 and 958 respectively. It is not known however how much heartwood, if any, was removed from the planks during their production (see also results for Structure 5, for example). 8071 was felled after AD

935, and therefore could be contemporary with the other timbers.

Because the dating thus obtained was very inconclusive, three additional samples were cut from timbers which were conserved for display in the Jorvik Viking Centre in York (8314, 8340, 8376). The combination of short ring sequences, knots and impregnation by polyethylene glycol, rendered 8314 and 8340 unsuitable for dating, but the north wall sill beam (8376) was dated. Its ring pattern spans the period 915-970, and its sapwood transition was dated to 958. It was therefore felled in the period 970-1008.

c) Structure 3 - south compartment of the Area 4/1 two-roomed building

Timbers with a variety of functions were examined from this building: two west wall sill beams (8392, 8394); two braces from the east wall (8882, 8888), a north-east corner post (8359) and a partition beam (8393). Two planks (8859, 8860) from the drain associated with the building (Fig 1), and a timber from the top of the backfill (8865) were also examined.

The timbers came from young trees which were aged between 60 and 100 years when felled. The trees were relatively small and immature compared to those used to produce radial planks for some of the sunken buildings. Their diameters are roughly in the range of 140 to 300mm.

8393 and 8888 were hewn on two sides to produce rectangular timbers. They retained all their sapwood on the other two sides. 8359, 8394 and 8865 were similar but had most of their sapwood removed; 8392 and 8882 were halved trunks. Two of the timbers (8359, 8865) were very knotty.

The ring patterns of 8394 and 8882 were almost identical, suggesting that they are two sections from the same tree. Their outer rings date to 961 and 957 respectively, giving a felling date after AD 971. The outer ring of 8888 is 1008. As the tree was probably felled in winter or early spring, its date of felling is late AD 1008 or early 1009. 8359 has a felling date of 989-1029, whilst the two drain planks were felled 988-1028. The ring sequence from 8393 appeared to match in two positions, but after much checking and re-checking, both in the Dendrochronology Laboratory and in the Department of Probability and Statistics at Sheffield, the date 930-987 was preferred. This gives a felling date 987 or just after, since the timber had all its sapwood but the outer edge may have been slightly damaged.

This structure therefore contains timbers from two periods (Fig 3): timbers 8882, 8393 and 8394 were felled in AD987 or just after, whilst 8359, 8888 and probably the two drain planks were felled in 1008/9. 8865 was undated so the date at which the structure went out of use cannot be determined.

d) Structure 5 - front Area 2

The six planks from this structure were not given timber numbers since they were intended for conservation rather than dendrochronology. The planks were taken to Sheffield, where cross-sections were carefully prepared with a Surform plane, and the ring widths measured. The timbers were then returned intact to the Conservation Laboratory in York (see Morgan et al 1981 for further details about dendrochronology and conservation). Because there was a difference in date between the two lower planks and those above them (see below), samples were also taken from four of the

east wall uprights.

The lower planks from the south and east walls (S1, E1) were tangentially split from relatively young trees, aged about 60-80 years, and with diameters of around 300mm. The remaining planks were radially split from larger, older trees. They were aged 150 years or more when felled, and those producing E2 and E3 had diameters of at least 700mm. The uprights were from whole (8556, 8559, 8563) or halved (8362) trunks which had been hewn into rectangular shape. The trees would have been similar in size and age to those producing S1 and E1. The only timbers with sapwood were S1 and E1, and possibly 8562. The latter may have had three sapwood rings, but the distinction between heartwood and sapwood was not clear enough to make a definite decision. (Although not generally a problem, the division between sapwood and heartwood is not always distinct - for more details, see Hillam 1986).

The inner rings of S3 were not measurable so only the outer 45 rings were measured. The ring pattern crossmatched well, however, with those from the other radially split planks. The curves from the tangential planks and the uprights matched each other, but there was no crossmatching between them and the radial sequences. This is not surprising since, when they were dated, there was in fact only 27 years of overlap between the two groups (Fig 3). S1 and E1 had heartwood-sapwood transitions of AD 946 and 948 respectively, giving felling dates 958-998 and 956-996 or, assuming them to be contemporary, 958-996. The uprights are also probably of this date, but a precise felling date cannot be given for the radial planks. S2 was felled after 917, whilst the others were felled after 886, 883 and 892.

There could be several explanations for the difference in date between the two groups. The planks could have been cut from the inside (the radial planks) and the outside (tangential) of a large oak tree, but the fact that the ring sequences of the uprights span a similar period of time to those of the two tangential planks suggests that two sizes of tree were used: smaller ones for the uprights and lower planks, and larger ones for the radial planks. That the radial planks were re-used or had been stored for several years cannot be ruled out, but a more likely explanation is that heartwood, as well as sapwood, rings were removed when the radial planks were prepared (compare Fig 3, Structure 5, with Baillie 1982 Fig 2.2b). This will be discussed in more detail below since the difference in date between radial and non-radial timbers occurs in other structures.

e) Structure 6 - front Area 4/1

The four timbers from Structure 6 were whole (8456, 8460) or halved (8464, 8465) trunks which had been hewn into rectangular shape. The sapwood was removed from all the timbers, except possibly for three rings on 8464.

They had between 45 and 76 growth rings. 8460 was rejected for dating purposes because its 45 complacent rings could not be dated with any reliability. The ring patterns from the other two bracing beams, 8464 and 8465, were synchronous. They, and that of the sill beam 8456, were tested against the other Coppergate ring sequences, as well as against various reference chronologies, but they were not dated.

f) Structure 7 - front Area 2, cavity wall building

Four planks (8675, 8676, 8702, 8708) and five posts (8692, 8693, 8695, 8696, 8701) were examined from the east wall. In addition, two posts (8827, 8833) which may have been associated with the building, and an un-numbered timber were analysed. Finally, a timber (8720) from a post alignment above the building was sampled to try and assess the length of time for which it was used.

Three of the planks (8675, 8676, 8702) were radially split from trees of about one metre in diameter. The trees were at least 290, 140 and 160 years old respectively when felled. The remaining plank (8708) was a halved trunk from a tree of about 400-500mm in diameter and aged about 80 years. The posts also came from trees less than 100 years old, and were probably of similar size to 8708. They were mostly halved trunks (eg 8696), but some (eg 8701) had been severely trimmed on each side.

When the ring patterns were compared visually, two groups again emerged. Those from the radially split planks formed one group, whilst the remainder formed a second group. A similar situation was found with the samples from Structures 2 and 5, except that only the radial sequences could be dated from Structure 2, and there was little overlap between the two groups from Structure 5. Although the two Structure 7 groups did not appear to match each other, both groups were dated and, unlike the Structure 5 timbers, their ring patterns cover similar periods of time. There is no doubt about their contemporaneity since they have similar heartwood-sapwood transitions (Figs 3, 4). These fall within the period 936-948, a range which is easily accounted for by the variation in sapwood number (Fig 2). The timbers are

therefore likely to have been felled in AD 961-986. 8827 with a heartwood-sapwood transition of 934 was probably also contemporary. The only possible exception is 8702, one of the radial planks, which ends in AD 918, and must have been felled after 928. It seems likely that its sapwood and about 10-20 heartwood rings were removed when it was converted into a radial plank.

The timber from the post alignment above Structure 7 (8720) dated to 795-931, but it has no sapwood. A felling date of after 941 is all that can be achieved, which gives no information about when the building went out of use.

g) Building 2 - Area 4/1, workshop with wood

Twelve horizontals, three sill beams and one brace were sampled from this workshop. Samples were also taken from a stave-built box construction (9020) and other associated timbers, including some from the backfill (Table 1g). Unfortunately, only the sill beam 9002 and its brace 9029 are definitely associated with the construction of the building (Hall pers comm).

The timbers were a variety of shapes and sizes. 9002 was a whole trunk trimmed on two sides. It was from a tree, with a diameter about 200mm, which was felled in the summer of its 107th year (ie the ring under the bark edge was incompletely formed). 9027 was a halved trunk and 8990 a quartered one, whilst 8995 and 9020 were radially split planks. It is unlikely that any of the trees exceeded 500-600mm in diameter or 150 years of age, and many must have been under 100 years old when felled. The only exception is 8995, but the sample contained a knot so its age cannot be determined. The timbers in the backfill were either

radial (8892) or tangential (8947) planks, or large timbers (8922).

Four samples (8975, 8990, 9028, 9030) were rejected because they had insufficient rings (usually less than 50 rings but, where a sample had full sapwood, patterns with more than 30 rings were measured). Another seven did not match either with each other or with other Coppergate tree-ring curves. The remaining sequences matched each other, and were all dated. Of the two timbers definitely from the construction phase, only 9029 could be dated. This gave a felling date of 960-994. However, with the exception of 8979, 9008 and the dated timbers from the backfill, the other dated timbers have similar outer rings or heartwood-sapwood transitions (Fig 4), and are probably contemporary. 8979 and 9008 have felling dates of 971-1011 and 965-1005 respectively, and may be later repairs or additions to the building. The most recent timber from the backfill (8947) was felled 991-1031, but the timber sealing the structure (8905) was undated, so again the life span of the building cannot be determined.

h) Building 3 - Area 4, plank-floored building

The five posts from this building (9000, 9133-5, 9146) were cut from trees over 200 years old. All but 9135 were thick radially split planks; 9135 was a halved trunk. The trees were not very large in diameter (370-700mm), but they were slow-grown with average ring widths of 0.73mm to 1.37mm.

The five ring patterns matched each other, although 9135 was less similar than the others, and they proved useful in obtaining the first tree-ring dates for the Viking Age timbers from Coppergate. The two timbers which retained some sapwood (9135, 9146), were felled 944-984 and 955-995. The others were

felled after 913, 944 and 947. There is no reason to suspect that the timbers were not contemporary, so the likely felling date for them is 955-984.

i) Warehouse

With the exceptions of 8653 and 8656, all the posts sampled for dendrochronology were worked whole trunks. Post 8656 was a round trunk of radius 80-90mm, whilst 8653 was a heavily trimmed helved trunk. The trees had diameters of about 400mm and were probably 90-120 years old when felled, except for 8656, which was much younger.

The latter timber was not used for dating as it had only 30 rings. The remaining ring sequences were all synchronous, and their ring widths were averaged to produce a working master curve. This master remained undated for several years because the ring patterns of it, and its constituent sequences, appeared not to be unique (Hillam 1986). The problem was solved when the Lincoln Cathedral chronology (Laxton et al 1982) became available. The two curves showed good agreement (t = 7.5) when the Coppergate curve covered the period AD 914-1011 (Fig 5). The timbers seem to be contemporary, and were felled in AD 1014-1054.

j) Strip between Building 2 and Structure 2

A squared post with sapwood was examined from the strip of land between the two structures (Fig 1). Its ring sequence dates to 908-966, and its heartwood-sapwood transition to 953. It was therefore felled during the period AD 966-1003, although the heartwood-sapwood date is more similar to those from the later phase of construction (Structures 2 and 3) than the earlier phase (Buildings 2 and 3).

Dating the sunken buildings

Timbers from nine structures were examined dendrochronologically, and tree-ring dates were obtained for all but Structure 6. As only three timbers (8387, 8393, 8888) had complete sapwood, it is necessary to look in more detail at the interpretation of the tree-ring dates. By examining the dates of the heartwood-sapwood rings or the last measured heartwood ring (Figs 3, 4), and the estimated felling dates (Fig 6), it is possible to provide a dating framework for the sunken building phase. As will be seen below, this should now be augmented by other archaeological evidence.

At least one timber for the Structure 1 workshop was felled in AD 972/3, and others may also have been felled at that time. The structure therefore is likely to have been built in AD 973 or very soon afterwards. The fact that other structures have similar felling dates suggests that timber storage and reuse were not important factors, whilst seasoning - other than through one or two year's storage - is unlikely. Even if the timbers were stored, for example, in a merchant's yard, the building was probably erected by the mid 970's AD. The dates for two of the timbers (8221, 8849) show that the building was repaired, and that this took place some time after 994 and 976 respectively. The timbers in the backfill were not felled before 997 and 1001, which suggests that the workshop was in use until at least AD 1001.

The dates of those timbers with sapwood from Structures 5 and 7, and Buildings 2 and 3, are consistent with these buildings being comtemporary with Structure 1, although this cannot be proved from the tree-ring evidence. Like the Structure

1 workshop, the workshop with wood (Building 2) may have been repaired, but the timber repairs (8979, 9008) occurred a little earlier than at Structure 1 (and it is just possible that the two timbers were part of the construction phase, but that had a small amount of sapwood). The timber with sapwood from the back-fill of Building 2 (8947) was not felled before AD 991. Other timbers which would have shown for how long the structures were in use either were not dated or had no sapwood.

The two-roomed structure, Structure 3) which overlies the workshop with wood, has two groups of felling dates: the west wall sill, east wall brace and partition beam were felled AD 987 or just after; the north-east corner post and a second brace from the east wall were felled in AD 1008/9. The building therefore cannot have been constructed before 987 which, assuming that the building underneath it, Building 2, was constructed in 973, gives the workshop a life span of at least 14 years. The drain associated with Structure 3 appears contemporary with the timbers felled in 1008/9, so the building may have been repaired, and a drain added, at that time.

The dating of 8376, the only timber with sapwood from the Structure 2 workshop, is similar to those timbers from Structure 3 which were felled about 987. The tree-ring evidence therefore suggests that Buildings 2 and 3 were replaced in AD 987 or just after by Structures 3 and 2, and that Structure 3 was repaired or renovated in AD 1008/9 or shortly afterwards.

The remains of the warehouse produced only one timber with sapwood so a precise felling date cannot be given. However the building must have been constructed after AD 1014 but before AD 1054.

These results are derived solely from the tree-ring evidence. The felling dates for those timbers with total sapwood are completely reliable, and provide a precise terminus post for the construction. The interpretation of the remaining tree-ring dates is based on the estimation of felling dates, using the best available sapwood estimate (although this may be refined in future years after the examination of more sapwood data). This provides a date range, or a terminus post quem, for the time of felling. Within this framework, possibilities of re-use, storage and repairs must also be considered. If other archaeological evidence, such as pottery, coins, stratigraphy, are taken into account, it may be possible to modify and refine the dating framework suggested by the tree-ring results.

The timbers

The timbers show a remarkable variety, not only in size but also in the way in which they were worked to produce the finished piece of timber. This does not seem to depend on the function of the timber, but may be dependent instead on the size of tree available. The size of tree, ie the diameter of the trunk, and the age at which it was felled (although the values calculated in this study must necessarily be very approximate), are also very variable, but what is apparent from the study of all the Viking Age timbers from Coppergate is that there are two main classes of trees (Table 3):

i) those producing radially split planks. They had diameters of at least 0.5m, and sometimes over 1m (eg Table 1f: 8676 from Structure 7), and were often over 200 years old when felled.

ii) those producing the remaining timbers, tangential planks or whole trunks. They were usually less than 0.5m in diameter,

usually less than 100 years old, and never more than 150 years old when felled. This is the type of oak tree which was felled until quite recently in coppice-with-standards woodland (eg Rackham 1980 frontispiece).

The ring patterns of the two types of timber are not very similar so that the radial planks and the other timbers from Structure 7, for example, do not crossmatch. They can however be dated within the framework of other Coppergate curves. This contrasts with the situation outlined by Fletcher (eg 1978), where he postulates two distinct chronology types, Type A and Type H.

It is probable that Fletcher's Type A chronologies are constructed from imported timber (Baillie 1984; Rackham 1982). It is unlikely that either of the Coppergate groups are imported since crossmatching is possible between some of them, and they match with other British chronologies. However the agreement between the two groups, when it occurs, is low enough to suggest that there are two different sources, and probably two different types, of woodland. It is therefore postulated that the radial timbers came from unmanaged woodland, whilst the younger timbers may have come from managed coppice-with-standards woodland. Furthermore the radial timbers came from trees subjected to more limiting conditions of growth than did the smaller trees. Because of this, the radial ring patterns were easier to date. It was always the other sequences which appeared not to be unique, and which made Coppergate a difficult site. The ring patterns generated by the more favourable growing conditions reflect more of the local environment, and less of the general climatic signal which is necessary for crossdating.

What is not clear is why two seemingly distinct sources of timber were used to construct some of the buildings (and the situation is more complex for the wattle phase of building because in that period there seems to be more than one source of radial timber). It is unlikely that the radial timbers are re-used from an earlier phase, as was first suspected from the results from Structure 5, because many of them are contemporary with the other type of timber. Some form of stockpiling or storage cannot be ruled out, especially if someone was selectively felling the large trees from unmanaged woodland. It is also possible that the woodlands in the more fertile areas were becoming exhausted, or were being destroyed. However the tree-ring results (Fig 3) are consistent with the two types of timber being felled at the same time. None of the radial planks that appear earlier have sapwood, so the seemingly early date is most likely due to loss of some heartwood rings during timber production (see also Baillie 1982).

Conclusion

Of the 104 timbers examined from the sunken buildings, 7 were rejected because they contained knots or had insufficient rings for dating. Seventy out of the remaining 97 timbers were dated. This represents a 72% success rate which is higher than average for a complex urban site, and far better than that obtained for the wattle phase or medieval timbers from Coppergate. It is particularly pleasing in view of the considerable difficulties involved in dating their ring sequences. Many of them appeared not to be unique (for example, those from the warehouse), and this has meant that many checks and cross-checks were needed to provide adequate replication of the ring

sequences. Replication, the matching of one ring pattern with several others in consistent positions, is the only way of ensuring reliability in tree-ring dating, particularly when the samples have less than 100 rings.

Despite these difficulties, felling dates were obtained for timbers from eight out of the nine structures. Structures 1, 5 and 7, and Buildings 2 and 3, were probably all constructed in, or shortly after, AD 973. Buildings 2 and 3 were in use at least 14 years before Structures 3 and 2 replaced them in AD 987 or just after. Structure 3 was repaired in 1008/9, and a drain was probably added at that time, whilst the Warehouse was built some time between 1014 and 1054.

The ring sequences provided evidence that two distinct types of timber were used: relatively large, long-lived oak trees produced radially split planks, whilst smaller, younger trees were used for the remaining timbers. The first group grew under conditions that were more limiting than those for the second group, and are less likely to have come from the fertile Vale of York. Other environmental evidence from Coppergate may reveal more information about the likely location of the woodlands.

From a dendrochronological point of view, the success rate for the dating of the sunken buildings timbers is impressive, especially when compared to that for the wattle and medieval phases. It reflects the fact that more timbers were sampled, and that more information was available. Although most of the undated timbers had 40-80 rings, many such timbers were dated (Fig 7), and it appears that the number of rings per sample is less important than the number of samples per structure. It is notable that many of the undated timbers from this phase are timbers from the backfills or other isolated timbers. If

these were excluded from the calculation, the success rate would be even higher.

This study shows that to obtain the best results from a complex site, every timber from every structure should be sampled, and the samples should be accompanied by adequate information about each structure. By grouping the timbers according to structure, they will be easier to date, and resulting dates will be more precise because they will be easier to interpret.

Acknowledgements

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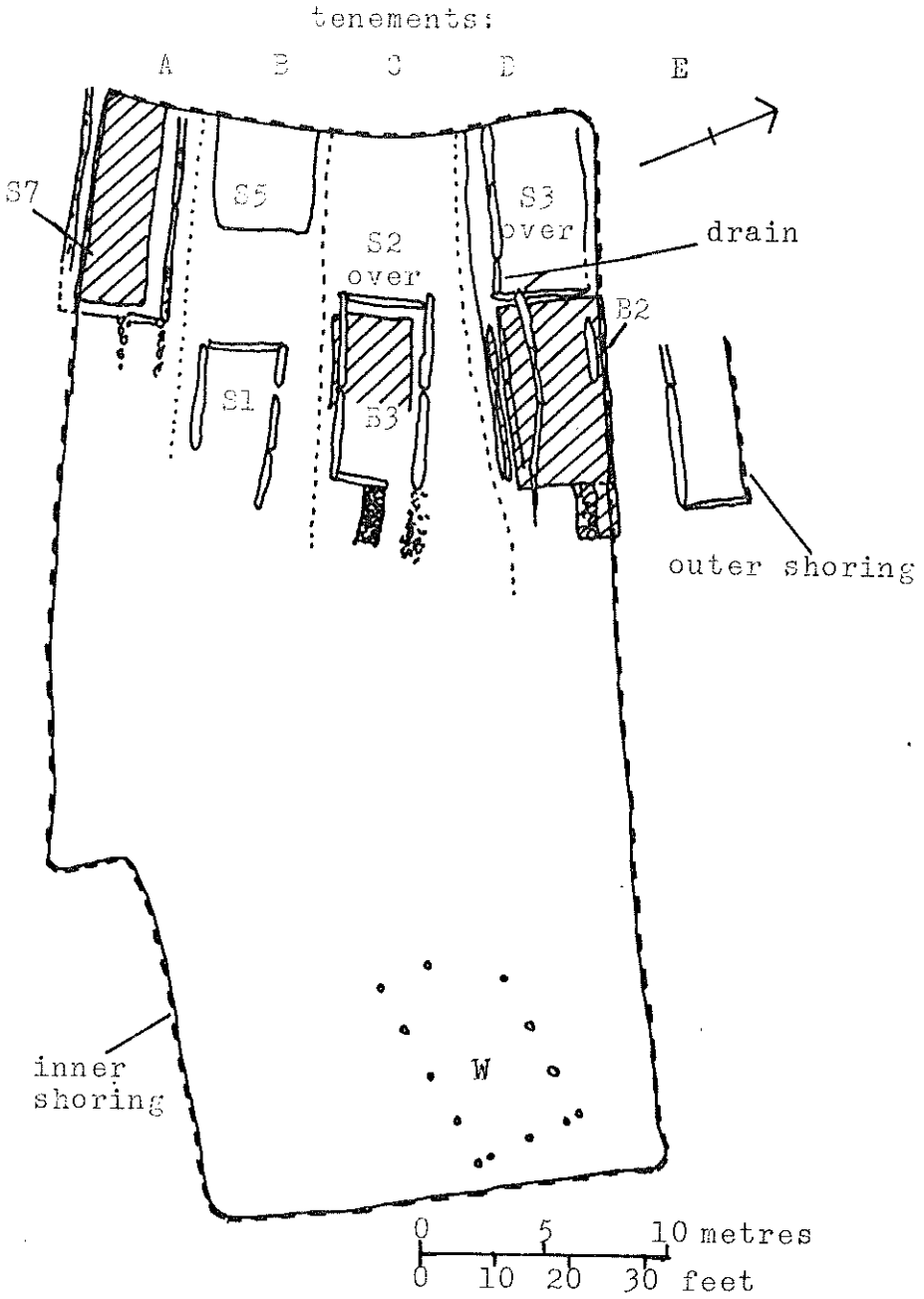


Fig 1: Coppergate during the sunken building phase. Features beyond the inner shoring are those recorded during the watching brief. B - Building; S - Structure; W - Warehouse. (after Hall 1984).

COPPERGATE

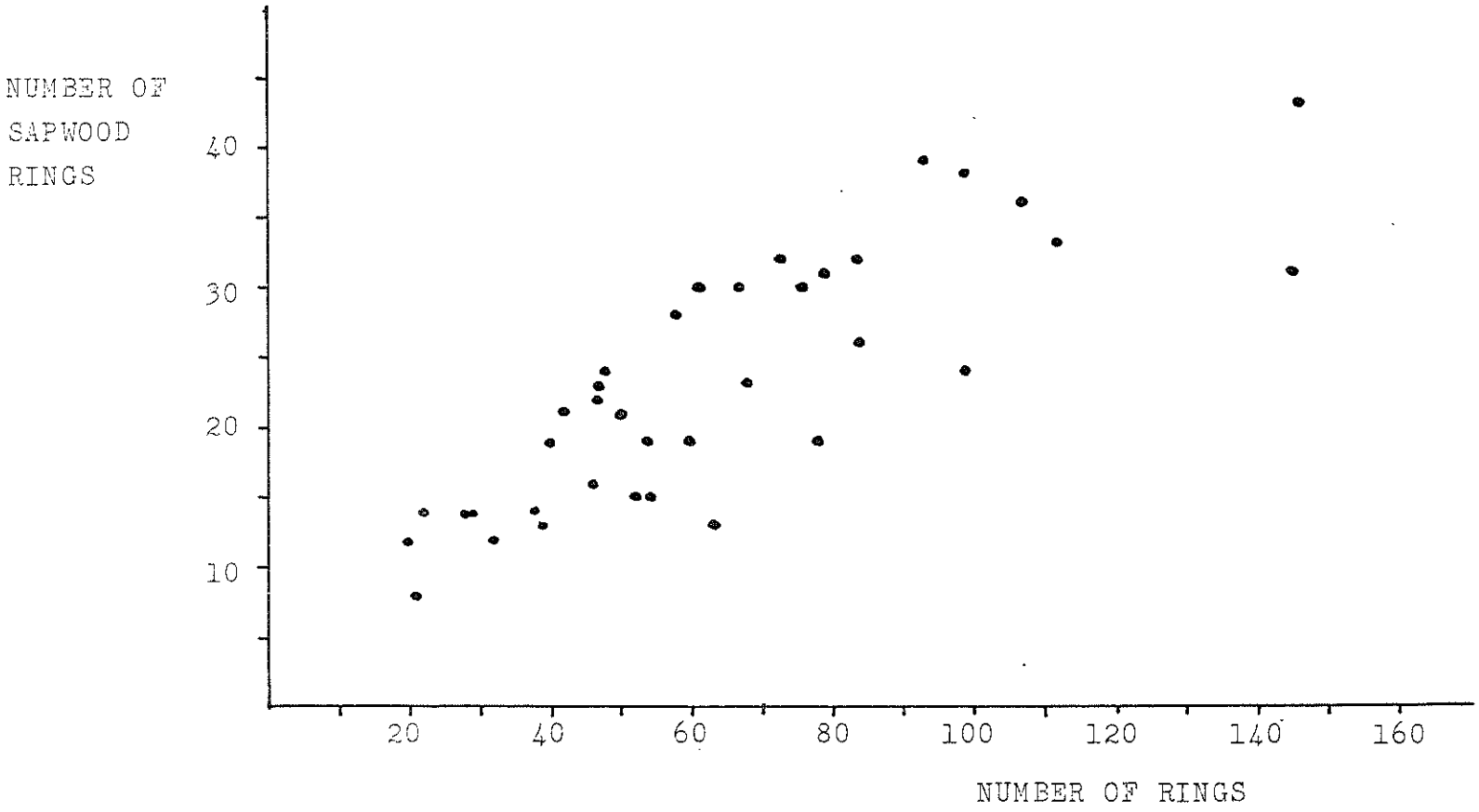


Fig 2: Variation in sapwood number with the number of rings for 37 samples from Coppergate. Note the increase in sapwood number with increasing age.

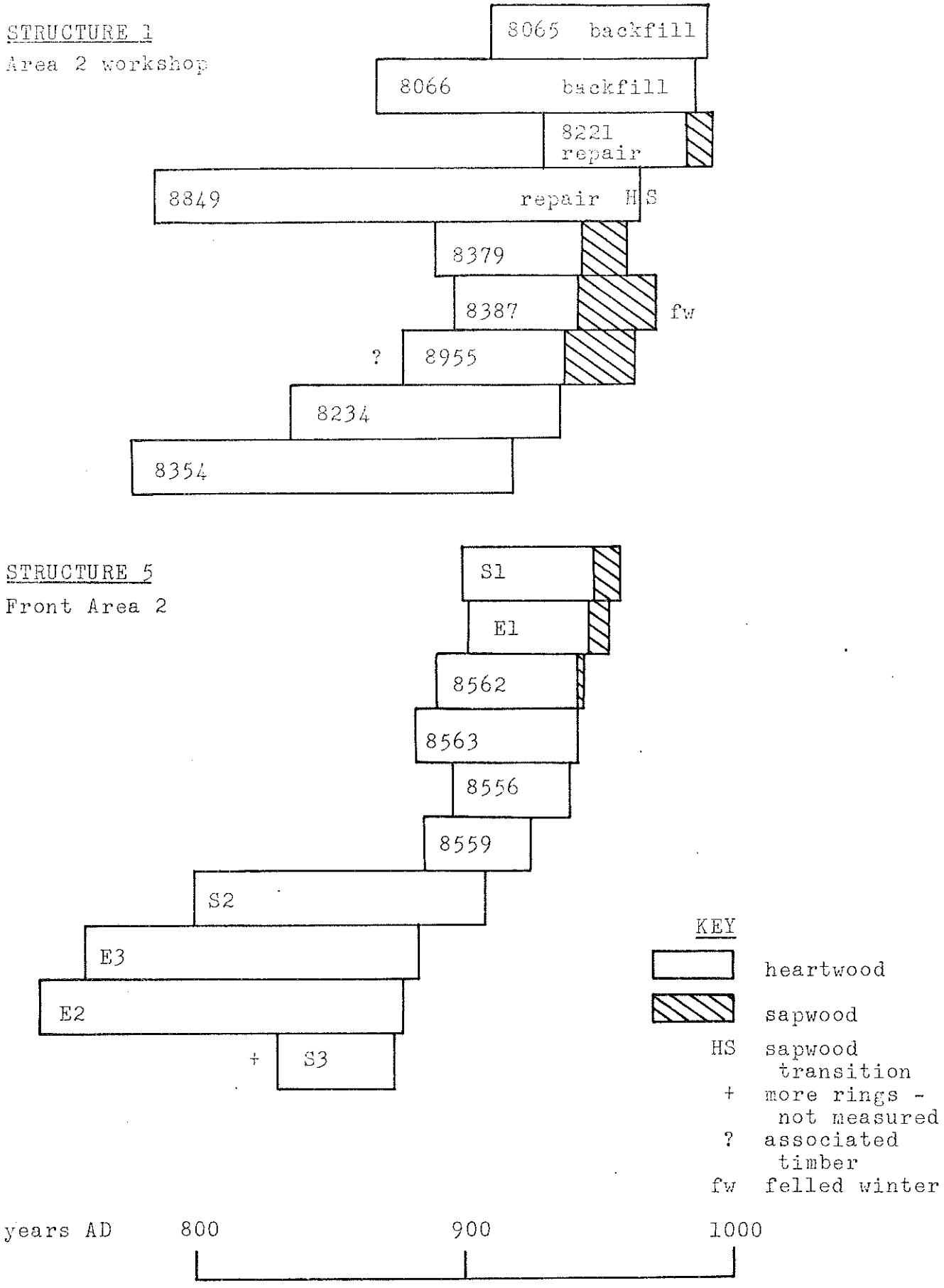
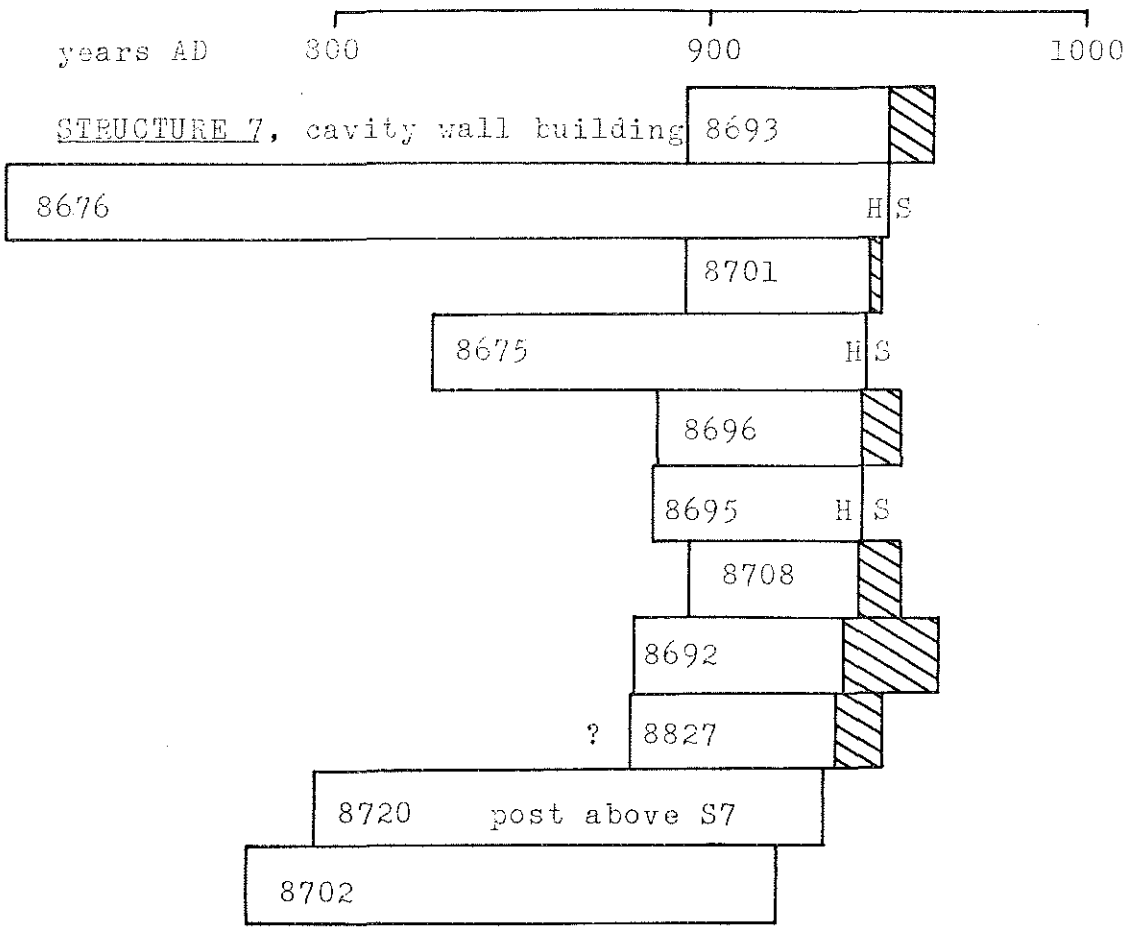


Fig. 3: Bar diagram showing the relative positions of the dated ring sequences. For further details of the timbers, see Table 1.

cont/


years AD
800
900
1000
STRUCTURE 7, cavity wall building
8693
8676
H S
8701
8675
H S
8696
8695
H S
8708
8692
? 8827
8720 post above S7
8702

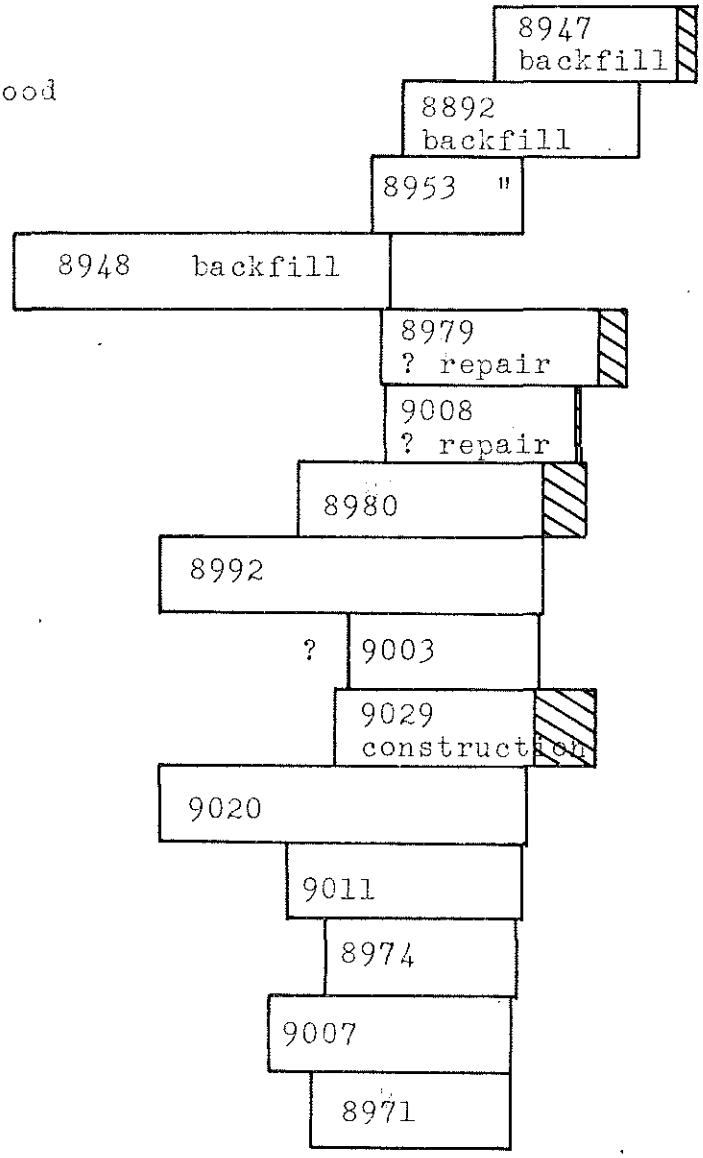
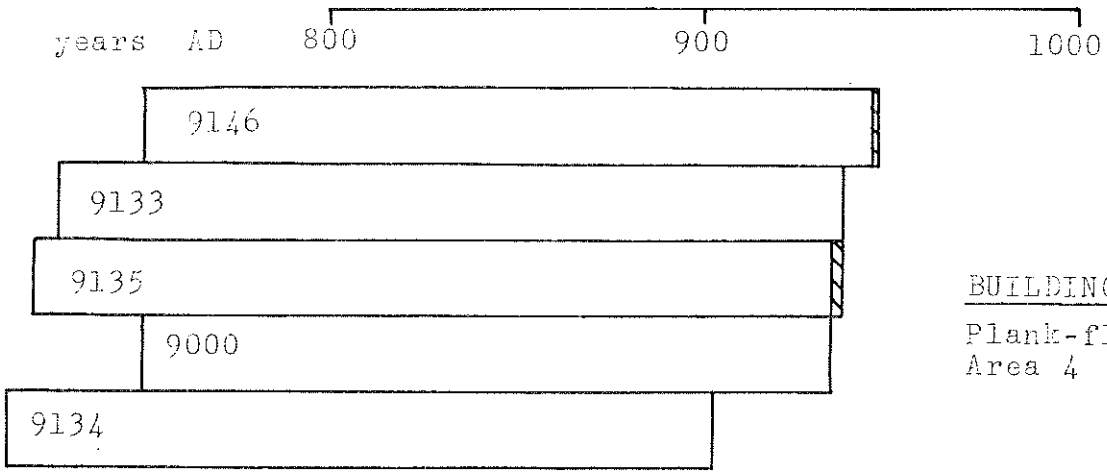

BUILDING 2
Workshop with wood
8947
backfill
8892
backfill
8953 "
8948 backfill
8979
? repair
9008
? repair
8980
8992
? 9003
9029
construction
9020
9011
8974
9007
8971

Fig 3/cont

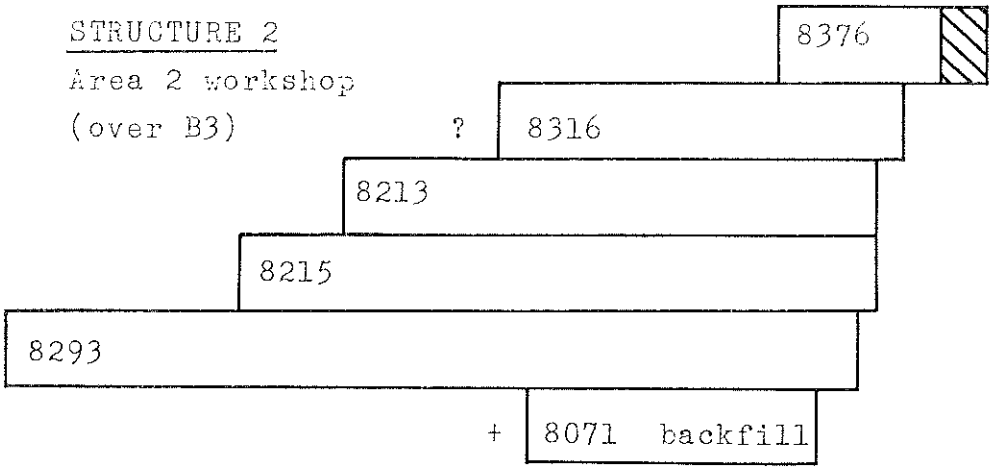


BUILDING 3

Plank-floored building,
Area 4

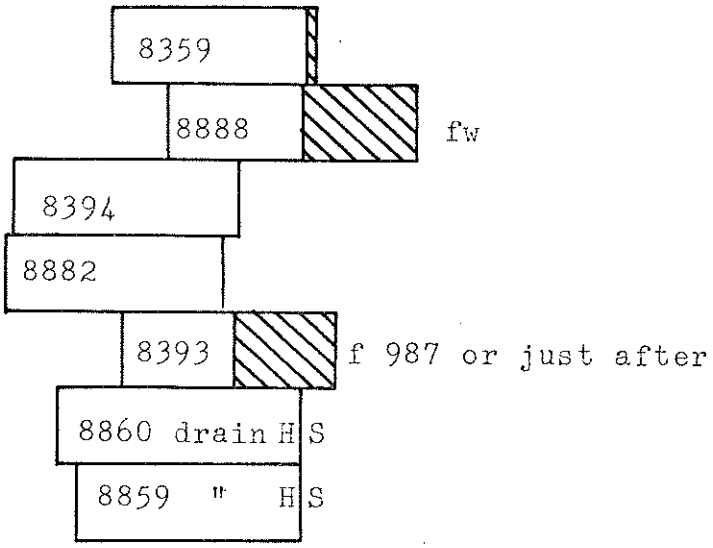
STRUCTURE 2

Area 2 workshop
(over B3)



STRUCTURE 3

Area 4/1, south compartment
of two-roomed structure
(over B2)



BETWEEN S2/B2

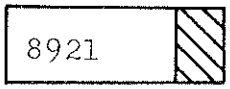
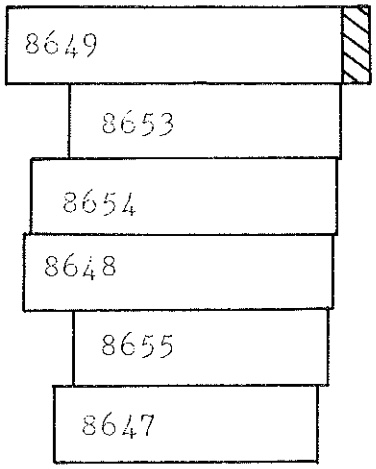


Fig 3/cont

Fig 3/cont

WAREHOUSE



COPPERGATE

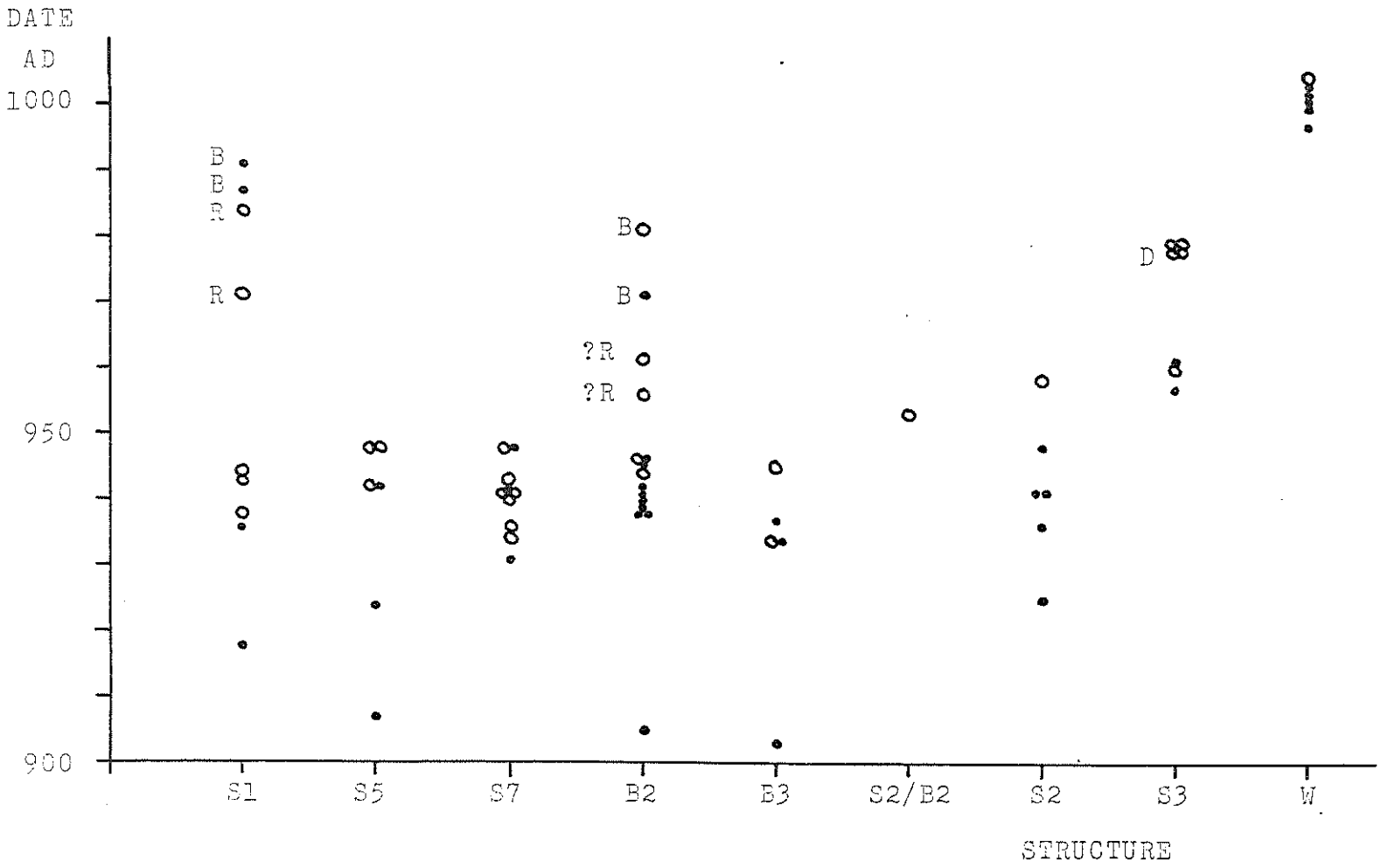


Fig 4: Dates of the heartwood-sapwood transition (open circles) or, if absent, of the last measured heartwood ring (solid circle). B - backfill; R - repair; D - drain; S - structure; B - building; W - warehouse. Note the cluster of dates between 930 and 950 for the first five structures.

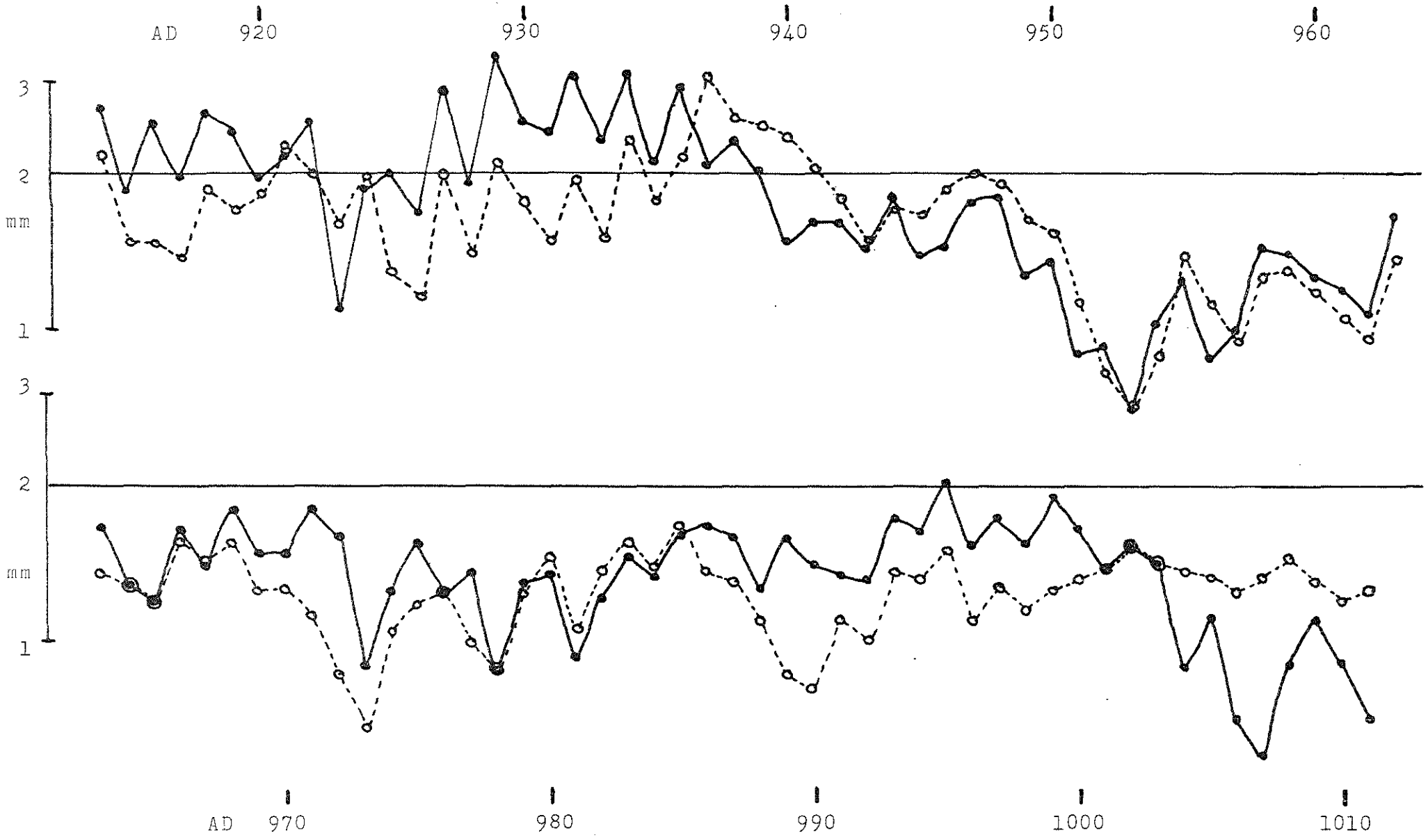


Fig 5: Dating the Warehouse master curve (solid line). The match with Lincoln Cathedral gives a t-value of 7.5. The Lincoln Cathedral data (broken line) was provided by the Nottingham Tree-Ring

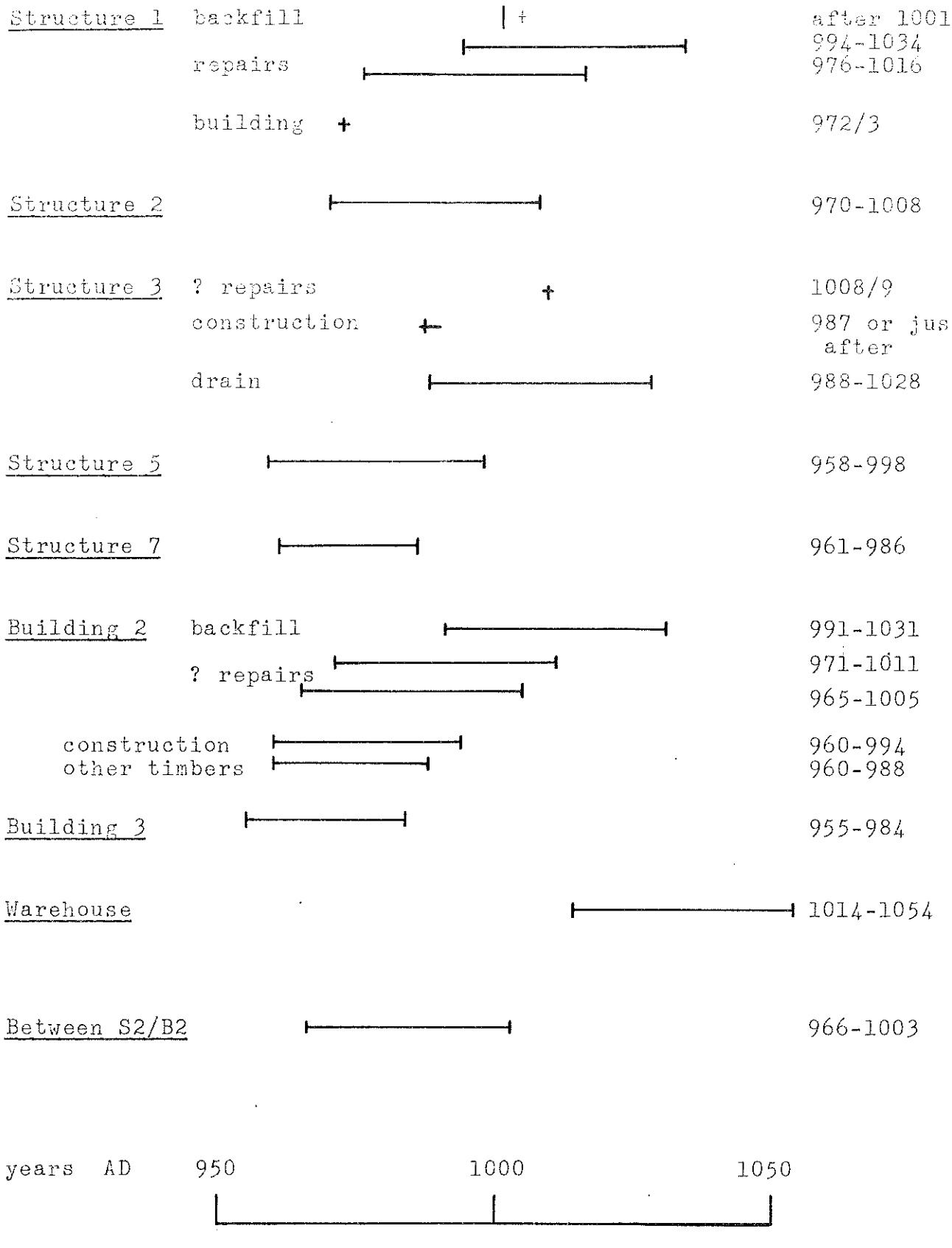


Fig 6: Estimated felling dates. The number of sapwood rings is taken as 10-50 rings.

COPPERGATE: TIMBERS FROM THE SUNKEN BUILDINGS

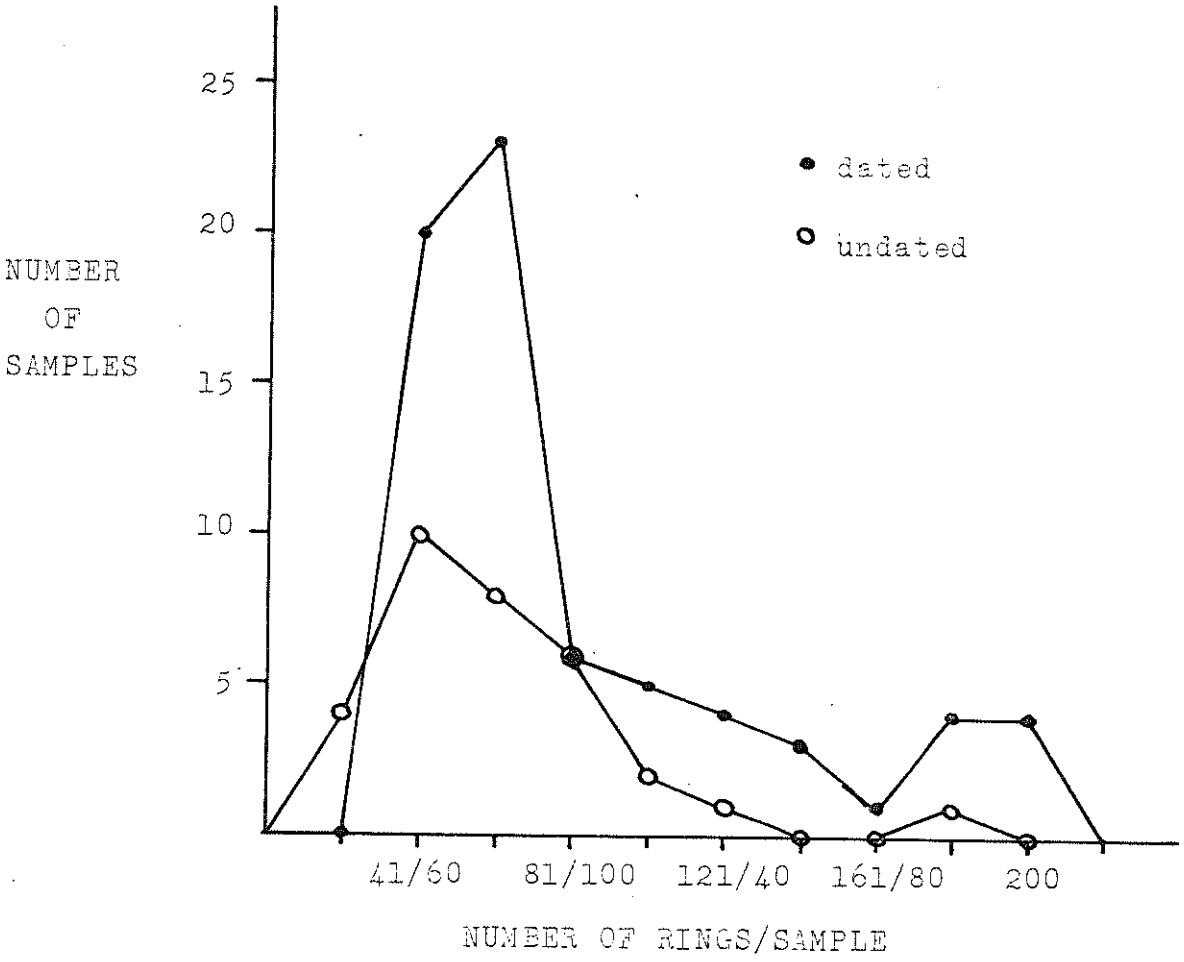
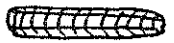
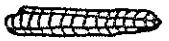
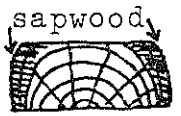
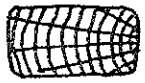
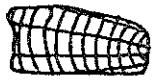


Fig 7: Relationship between the number of samples dated or undated, and the number of rings per sample.

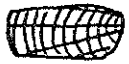
Table 1: Details of tree-ring samples from the sunken building phase. Sketches not to scale; dimensions are in mm; dates of heartwood-sapwood transition (if present) are given in brackets. Asterisks denote samples not used for dating. '+' - additional rings are present, but cannot be measured.

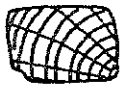
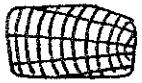
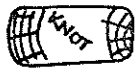
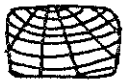
a) Structure 1 - Area 2 workshop

timber no	context no	function	total no of rings	sapwood rings	average ring width	sketch	maximum dimension	date of ring sequence
8065	2970	plank in backfill	82	-	2.52		210 x 30	910-991
8066	2955	plank in backfill	121	-	1.07		135 x 30	867-987
8105	2876	backfill	54	-	1.61		90 x 20	
8221	8201	north wall plank - late repair	64	10	2.05		280 x 65	930-993 (984)
8234	8038	east wall upright	102	-	1.11		200 x 105	835-936
8354	2777	west wall upright	144	-	0.79		220 x 130	775-918
8362	8658	west wall	98	5?	1.74		180 x 70	
8379	8047	east wall sill	73	18	1.69		280 x 170	889-961 (944)

8387	8744	west wall post	76	30	1.64		250 x 65	897-972 (943)
8849	8550	west wall sill	183	1	1.28		250 x 100	784-966 (966)
8955	8978/ 27319	post - may not be part of structure	88	27	1.26		200 x 160	877-964 (938)

b) Structure 2 - Area 4 workshop

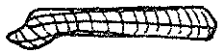
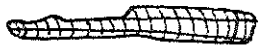
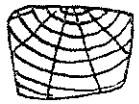
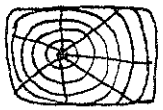
8071	7047	in backfill	+78	-	1.07		140 x 100	+848-925
8075	7096	in backfill	58	-	1.31		80 x 60	
8156	7085	north wall post	84	10	1.39		210 x 100	
8157	7240	north wall horizontal - ?collapsed wall plank	+72	-	1.43		120 x 80	
8213	7081	west wall plank	143	-	1.67		180 x 35	799-941
8214*	7089	west wall	30	13	-		radius 90	
8215	7319	west wall plank	171	-	1.51		250 x 40	771-941
8275	7091	east wall upright	50	7?	2.40		240 x 120	

8293	7306	west wall plank	228	-	0.90		210 x 40	709-936
8314*			-	?	-		220 x 80	
8316	7448	piece of timber on west wall sill	109	-	1.15		140 x 110	840-948
8319	1488	west wall upright	84	4	1.79		260 x 100	
8320	1487	west wall upright	74	-	2.59		190 x 100	
8340*			+46	-	-		285 x 110	
8360	7547	west wall upright	+78	-	0.91		210 x 90	
8376		north wall sill beam	56	13	1.87		205 x 55	915-970 (958)
8470	14257	?sill beam fragment in backfill of north room	73	-	1.12		200 x 90	
8475*	7557	collapsed upright	37	-	3.51		230 x 100	

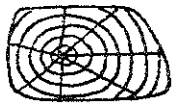
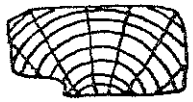
c) Structure 3 - two-room structure, south compartment

8359	9403	north-east corner upright	55	3	2.08		210 x 140	927-981 (979)
8392	1582	west wall sill	57	-	2.17		275 x 140	
8393	1600/ 1385	partition beam	58	28	1.99		210 x 120	930-987 (960)
8394	1587	west wall sill	61	-	1.98		240 x 160	901-961
8859	21890	plank from dog-leg drain below structure	61	1	4.20		270 x 40	918-978 (978)
8860	21891	"	66	1?	3.46		230 x 30	913-978 (?978)
8865	21797	top of backfill	60	1	0.79		170 x 110	
8882	9691/ 21794	east wall brace	59	-	2.19		220 x 110	899-957
8888	21796	east wall brace	67	30	1.06		140 x 90	942-1008 (979)

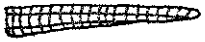
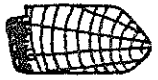
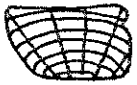
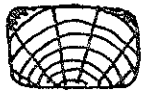
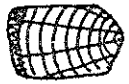
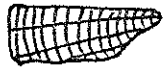
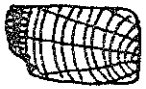
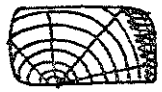
d) Structure 5 - front area 2

S1	south wall plank	60	11	2.13		270 x 60	899-958 (948)
E1	east wall plank	54	9	2.32		295 x 55	901-954 (946)
S2	plank above S1	110	-	1.54		230 x 40	798-907
E2	plank above E1	137	-	2.33		335 x 25	740-876
S3	plank above S2	+45	-	1.26		165 x 30	+829-873
E3	plank above E2	+126	-	1.92		320 x 30	757-882
8556	east wall upright	45	-			200 x 125	895-939
8559	east wall upright	41	-			200 x 115	884-924
8562	east wall upright	56	3?			190 x 110	889-944 (?942)
8563	east wall upright	62	-			190 x 110	881-942

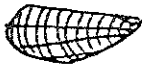
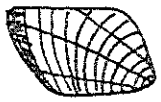
e) Structure 6 - front area 4/1

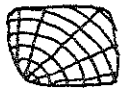
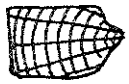
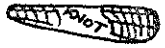
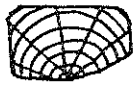
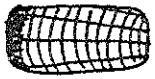
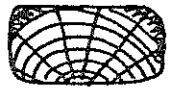
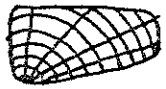
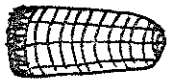
8456	14065	sill beam	60	-	1.47		190 x 80
8460*	14213	bracing beam	45	-	-		250 x 130
8464	14214	bracing beam	76	3?	2.37		330 x 120
8465	14219	bracing beam	71	-	2.24		320 x 140

f) Structure 7 - cavity wall building

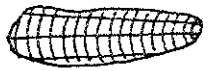
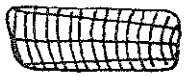
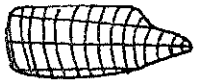
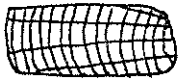
8675	20025	east wall plank	+230	1	1.34		370 x 30	713-942
8676	20644	east wall plank	123	1	3.38		400 x 30	826-948
8692	20033	east wall post	82	26	2.01		300 x 100	880-961 (936)
8693	20601	east wall post	66	13	2.04		150 x 100	895-960 (948)
8695	20237	east wall post	57	1	2.09		210 x 120	885-941 (941)
8696	20738	east wall post	65	11	2.19		235 x 100	887-951 (941)
8701	20600	east wall post	53	4	2.13		120 x 110	894-946 (943)
8702	20039	east wall plank	142	-	2.54		360 x 45	777-918
8708	20735	east wall plank	57	12	2.61		330 x 80	895-951 (940)
8720	20705	post alignment above structure	139	-	1.54		200 x 90	795-931
8827	20519	paired post - ?may be not be associated with construction phase	68	13	1.70		130 x 120	879-946 (934)
8833	20405	post associated with structure	85	-	1.49		140 x 50	
-	-	timber from structure	77	12	1.64		290 x 80	883-959 (948)

g) Building 2 - Area 4/1 workshop with wood

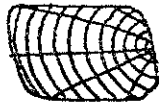
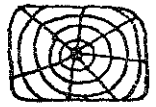
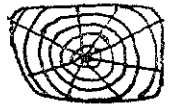
8892	29097	backfill	64	1?	2.33		150 x 30	908-971
8905	29127	horizontal sealing building 2	76	16-34	1.25		200 x 130	
8922	21976	backfill	187	-	1.18		230 x 110	
8947	29460	backfill	54	5	1.62		220 x 60	933-986 (981)
8948	29263	backfill	101	-	1.48		170 x 30	805-905
8949	29464	backfill	76	-	1.48		230 x 100	
8953	29469	backfill	41	-	3.79		210 x 70	900-940
8971	29546	horizontal	54	-	1.92		230 x 70	885-938
8974	29542	horizontal	51	-	2.16		260 x 120	889-939
8975*	29536	"	49	-	-		310 x 165	
8979	29626	horizontal associated with structure	66	8	2.13		200 x 80	903-968 (961)
8980	29600	horizontal	77	12	2.48		190 x 100	881-957 (946)

8990*	28547	horizontal	38	-	-		125 x 85	
8992	29555	"	103	-	1.73		170 x 100	844-946
8995	29537	"	+100	-	1.18		230 x 25	
8997	29539	"	87	2	1.19		135 x 110	
9002	29518	sill beam	106	35	1.05		220 x 160	
9003	29508	may be associated with building's construction	51	-	3.38		290 x 130	895-945
9007	29512	horizontal	65	-	2.56		260 x 100	874-938
9008	29513	associated timber - horizontal	53	2	2.47		130 x 45	904-956 (955)
9011	29543	horizontal	63	-	2.32		230 x 110	879-941
9020	29605	part of stave built box construction	99	-	1.99		210 x 40	844-942
9027	29519	sill beam	82	8	2.20		330 x 100	
9028*	29601	sill beam	42	-	-		140 x 100	
9029	29773	brace for sill 9002	70	17	3.19		210 x 70	891-960 (944)
9030*	29813	support for 9027	37	5	-		205 x 50	

h) Building 3 - Area 4 plank-floored building

9000	29564	post	184	-	1.16		220 x 70	751-934
9133	29562	post	210	-	1.37		280 x 110	728-937
9134	29563	post	189	-	1.18		210 x 100	715-903
9135	29567	post	216	4	0.73		240 x 120	722-937(934)
9146	35246	post from west wall	196	2	1.29		240 x 100	751-946(945)

i) "Warehouse"

8647	19122	west wall post	71	-	1.64		210 x 140	927-997
8648	19123	west wall post	83	-	1.62		210 x 130	919-1001
8649	19124	west wall post	98	8	1.48		250 x 150	914-1011(1004)
8653	19210	south east corner post	73	-	1.64		140 x 130	931-1003
8654	19121	west wall post	82	-	1.54		220 x 140	921-1002
8655	19248	west wall post	69	-	1.58		240 x 140	932-1000
8656*	19230	south wall centre post	30	6	2.31		radius 80-90	

j) Between Structure 2 and Building 2

8921	21958	post in strip between the two structures	59	14	1.49		150 x 150	908-966 (953)

Table 2: Felling dates of the individual timbers. Sapwood estimate is 10-50 rings; H/S - heartwood-sapwood transition.

no	date range	H/S	felling date	comments
Structure 1 (Area 2 workshop)				
8065	910-991	-	after 1001	backfill
8066	867-987	-	after 997	"
8221	930-993	984	994-1034	repair
8849	784-966	966	976-1016	repair
8234	835-936	-	after 946	
8354	775-918	-	after 928	
8379	889-961	944	962-994	
8387	897-972	943	972/3	sapwood complete
8955	877-964	938	964-988	? associated timber
Structure 2 (Area 4 workshop)				
8071	+848-925	-	after 935	backfill
8213	799-941	-	after 951	
8215	771-941	-	after 951	
8293	709-936	-	after 946	
8376	915-970	958	970-1008	
8316	840-948	-	after 958	associated timber
Structure 3 (2-room structure)				
8359	927-981	979	989-1029	
8393	930-987	960	987 or soon after	
8394	901-961	-	after 971	
8882	899-957	-	after 967	
8888	942-1008	979	1008/9	sapwood complete
8859	918-978	978	988-1028	drain timber
8860	913-978	978?	988-1028	"
Structure 5 (front area 2)				
S1	899-958	948	958-998	
E1	901-954	946	956-996	
S2	798-907	-	after 917	
E2	740-876	-	after 886	
S3	+829-873	-	after 883	
E3	757-882	-	after 892	

cont/

Table 2/cont

Structure 5

8556	895-939	-	after 949	
8559	884-924	-	after 934	
8562	889-944	942?	after 954 (or 952-992)	
8563	881-942	-	after 952	

Structure 7 (cavity wall building)

8675	713-942	-	after 952	
8676	826-948	-	after 958	
8692	880-961	936	961-986	
8693	895-960	948	960-998	
8695	885-941	941	951-991	
8696	887-951	941	951-991	
8701	894-946	943	953-993	
8702	777-918	-	after 928	
8708	895-951	940	951-990	
8720	795-931	-	after 941	post alignment over S7
8827	879-946	934	946-984	post- ? not associated with construction

Building 2 (workshop with wood)

9029	891-960	944	960-994	construction timber
8971	885-938	-	after 948	
8974	889-939	-	after 949	
8979	903-968	961	971-1011	associated timber
8980	881-957	946	957-996	
8992	844-946	-	after 956	
9003	895-945	-	after 955	? associated timber
9007	874-938	-	after 948	
9008	904-956	955	965-1005	associated timber
9011	879-941	-	after 951	
9020	844-942	-	after 952	
8892	908-971	-	after 981	backfill
8947	933-986	981	991-1031	"
8948	805-905	-	after 915	"
8953	900-940	-	after 950	"

cont/

Table 2/cont

Building 3 (plank-floor building)

9000	751-934	-	after 944
9133	728-937	-	after 947
9134	715-903	-	after 913
9135	722-937	934	944-984
9146	751-946	945	955-995

Warehouse

8647	927-997	-	after 1007
8648	919-1001	-	after 1011
8649	914-1011	1004	1014-1054
8653	931-1003	-	after 1031
8654	921-1002	-	after 1012
8655	932-1000	-	after 1010

Between Structure 2 and Building 2

8921	908-966	953	966-1003

Table 3: Summary of the sunken building timbers. Estimation of tree age and diameter is only very approximate.

structure	samples	dated	felled	comments on the timbers
1	11	9	972/3	large trees; aged either 70-100 yrs or over 200 repaired after 976 & 994 backfill timbers - after 997, 1001
2	18	6	970-1008 (as S3?)	posts 100-150 yrs; planks over 200; various sizes; posts & planks - different source of timber?
3	9	7	987 or just after	all small trees, 140-300 mm; 60-100 years repaired - & drain added? - 1008/9
5	10	10	958-996 (as S1?)	1. tangential or whole timbers - small young trees 2. radial planks - larger, older trees
6	4	-	-	worked whole or halved trunks
7	13	11	961-986 (as S1?)	1. radial planks - over 1m diameter 2. posts & 1 plank - less than 100 yrs, 400-500mm diameter. Two sources of timber?
building 2	26	15	960-994 (as S1?)	various sizes and ages backfill timber - after 991
building 3	5	5	955-984 (as S1?)	all over 200 years; slow-grown trees - not very large
between S2/B2	1	1	966-1003	whole trunk; diameter under 1m, less than 100 yrs
warehouse	7	6	1014-1054	mostly whole trunks; 90-120 yrs old, diameters circa 400mm

Appendix

Codes for sunken buildings (Period 5b)

Structure	Area	Tenement	Code	Comment
1	2	B	5/4	
2	4	C	5/6	over 5/5
3	4/1	D	5/8	rear over 5/7
4	4/1	D	5/11	over 5/8 front - no timber samples
5	2	B	5/3	
6	4/1	D	5/10	over 5/8 front
7	2 west	A	5/1	over robbed building 5/2
Building 2	4/1	D	5/7	
Building 3	4	C	5/5	
Warehouse		C?	5/12	
watching brief building		E	5/9	see later report

Tenements A-E run from south to north (see Fig 1).