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TREE-RING DATING AT GOLDSMITH STREET, EXETER

Ruth A. Morgan

Goldsmith Street, part of the Guildhall site in Exeter, was excavated by John Collis in 1971 (Collis, 1972). Several of the medieval levels contained pits lined with boards of wood, sections of many of which were brought to Sheffield for dendrochronological analysis. At that time, ring-width measurement and attempts at cross-matching produced few significant results and no dating, despite the good quality of much of the material; re-examination of the oak boards and matching of their patterns in 1978 has now enabled some of them to be dated by means of reference tree-ring material which has only become available in the last few years. This includes chronologies from Exeter itself (Hillam, 1979a), from Northern Ireland (Baillie, 1977a) and Dublin (Baillie, 1977b), and from south-east England (Fletcher, 1977); in addition there are curves for several regions of Germany which are sometimes applicable in Britain (e.g. Hollstein, 1965; Huber & Giertz-Siebenlist, 1969).

The work by Hillam at Sheffield on oak timbers from Trichay Street in Exeter, an adjacent site some 70m to the south-west, proved that accurate dating was possible by excellent cross-matching with, in particular, the Dublin chronology (Hillam, 1979a). Hitherto, no tree-ring work had been done in the South-west, and the relationships between growth patterns were unknown. Thus the Goldsmith Street timbers offered an opportunity to compare the growth patterns from the two sites and to assess their relationship in time, as well as to place an absolute time scale on the archaeological deposits of the Goldsmith Street site. A certain amount of dating has been possible and is described here; in addition tree-ring analysis of beech wood from the site has suggested the dendrochronological potential of this relatively unknown timber in England.

The Goldsmith Street timber

Details of most of the sampled timbers from the site are given in Table 1, which includes both those with sufficient rings for measurement and those that were too young. Not included are a number of small radial boards all of similar dimensions, which had extremely narrow or very few growth rings. Many of the boards appeared to have split longitudinally into smaller pieces since their use (which happens easily when they are thin), resulting in useless disjointed tree-ring sequences.

Most of the samples proved to be from good quality radial boards of oak (Quercus sp.) up to 270mm in width. Quality is shown in the quite narrow (1-2mm) but variable growth rings, indicating an origin in mature straight-grown oaks. A large group of such boards came from context 41-54-12, a wood-lined well (F315M).

A few timbers were quartered trunks hewn to a square cross-section from less mature trees, e.g. 35-40-2 B and C, while another group resembled half a thick tangential board particularly from the 43-40 area, a 16th century pit (F223). Fig.1 illustrates the structure of oak and the different conversion methods.

Eight timbers retained some outer sapwood, the significance of which will be discussed later.

As well as the oak, there was one radial board of hazel (Corylus) and three thin boards of beech (Fagus), the ring-widths of which were measured in a first attempt to assess the potential of this species for tree-ring dating in Britain. They came from a 16th century pit (F228) with a number of oak boards.

Methods of tree-ring analysis

Sample numbers can be related to the grid on which the site was excavated (Collis, 1972); the first two numbers indicate the coordinates of a 2m square in the grid and represent the horizontal dimension, while the third is the layer number within the 2m square. Any subsequent number or letter simply gives the order of tree-ring examination.

The still wet samples were sawn to a thin cross-section of about 5-7cm, washed and deep-frozen; in this state, the surface could be cleanly cut with a plane (Stanley surform) while the wood is supported in a vice. The clear annual rings were measured beneath a microscope (x10), the wood being placed on a long travelling stage. As each ring is traversed, the distance is measured by an electronic device (linear transducer) and recorded on a digital panelmeter, to be transferred by hand to printed data sheets. The values are also plotted as a graph on semi-logarithmic recorder paper, for use in visual matching.

Correlation by computer analysis supports and confirms any possible visual matches; the printout gives a Student's t value for each position of overlap between two curves. A match might be indicated by values in excess of 3.5, but must always be thoroughly checked by eye by overlaying the curves. Some examples of t values are given in Table 8; for more details, see Baillie & Pilcher (1973).

Results on the oak boards

Attempts to cross-match the oak ring-width curves soon revealed several probable single tree groups i.e. several boards which were split from the same tree and thus have almost identical growth patterns. It is usual to average these initially into a mean curve representing one tree, in order not to bias further averages by their greater numbers. This applied to six boards (A-F) from context 49-36-6 (F217M, lining of a deep pit) which could be dated(Fig 2), and six from context 41-54-12 (A,E,F,H,J,S) which are represented by mean curve 2 and are not dated (upper Fig. 3). One tree could produce many such boards, some of which were only 10mm thick; Fig. 1 gives some indication of how they were split from the tree along the rays. The boards from 49-36-6 varied considerably in thickness, while those from 41-54-12 were all very thin.

Mean curves were calculated from each of the tree groups; these could then be compared with the other individuals. Many of the timbers produced rather short curves for potential dating, with less than 100 rings, and indeed many of these still remain undated; it is essential however that they are examined. Such immature timber forms a large proportion of archaeological material, and has on a number of occasions proved extremely informative (e.g. Hillam & Morgan, 1979).

The presence within one excavated feature of boards both from the same tree and of unmatched boards with different growth rates suggests either a variation in the original sources of material, or a certain amount of reuse. Sufficient samples were examined from context 41-54-12 to illustrate this point (Table 2). The group already mentioned, of 6 boards, came from a slow-grown tree probably more than 250 years old and more than 300mm in diameter (based on board width). Boards B and P come from a very slow-grown but more sensitive tree over 350mm in diameter. The very narrow rings of both these trees are indicative of the stress conditions under which they grew, perhaps on higher altitude hill slopes or dense forest. In addition, there are 9 other boards of varying type used in this feature, of which two have been dated; four include large amounts of sapwood and suggest trees of the order of 100-120 years of age, perhaps 250mm in diameter, and with greater average ring-widths.

Resulting from the examination of the oak boards are three mean curves (formed by simple arithmetic averages of the individuals), one of which has been dated absolutely, and numerous short undated individual curves which do not match each other or any reference material available. The reasons for this lack of correspondence in the growth patterns are not clear, although similar problems occur regularly on urban sites where extensive tree-ring work is being carried out in medieval levels (e.g. York -Hillam, 1979b, and London - Hillam & Morgan, 1979).

Possibilities include:

1) Varied topography, leading to micro-environmental conditions and thus considerable variations in tree growth even within a small area.

2) The import of timber from other parts of Britain or Western and Northern Europe, which became widespread by the medieval period.

3) The reuse of timber taken from dismantled structures. This is clearly the case with the 11th century timbers in mean curve 1, which were discovered in much later contexts.

Timbers from a number of Devon cruck-framed buildings are also currently being examined (Morgan, unpub), and they too are extremely varied in growth rate and are as yet undated. Otherwise, the area is unknown dendrochronologically - no modern growth curves have even been studied to ascertain over how wide an area cross-matching might be possible.

A description of the three mean curves is accompanied by block diagrams illustrating the relationship of their components (Figs. 2-3) and tables listing the ring-width values (Tables 5-7).

<u>Mean curve 1</u>: this is based on 10 boards. It extends over 248 years and details of the boards included in it are found in Table 4 and Fig. 2. The curve was absolutely dated by excellent matches with curves for Trichay Street in Exeter, Dublin and South-east England, for which the <u>t</u> values are given in Table 8. It spans the period AD 775 to 1022. The table lists <u>t</u> values also for matches between Trichay Street and the reference material, which introduces different relationships. Trichay Street shows an exceptional match with Dublin, particularly when its length is taken into consideration. It also shows a much better match with York than Goldsmith Street. It seems likely that the timbers on each site came from different sources.

Compared to the other two mean curves, mean curve 1 has a very variable growth rate and thus relatively high mean sensitivity (Table 3).

Fig. 2 illustrates how the felling dates of the individual timbers are ascertained. The amount of preserved sapwood is shown by hatching. Oak sapwood maintains a fairly regular width of about 20-30 years, depending on tree age and average ring-width, and so the presence of only one sapwood ring allows an estimate of the approximate year of felling to be made. The dotted lines on Fig. 2 indicate the estimated amount of sapwood.

Boards 35-40-2 A/D retained 11 sapwood rings, and the very mature tree in which they originated was probably felled around AD 1040 (the feature in which they were found, F201, was dated archaeologically to the 15th century). Of the 49-36-6 group, only board A has a trace of sapwood which dates the felling of the tree also to around AD 1040. The wood in these two features, F201 and F217M, is thus contemporary almost to the year. It should be noted also that AD 1040 was the estimated felling date for timbers from F320 and F347 at Trichay Street (Hillam, 1979a).

Board 41-54-12 C has 19 sapwood rings and an estimated felling date of c. AD 1020. Board R from the same context was probably felled after about AD 1010; the minimum amount of missing wood is indicated by an arrow in Fig. 2. These timbers may also be evidence of reuse, since the well in which they were found may date archaeologically to the 15-16th century; further evidence would be found if mean curve 2 could be dated.

Board 47-40-14 also lacked sapwood and the tree must have been cut after about AD 980 - it is impossible to estimate the amount of missing heartwood and to determine how soon after.

Mean curve 1 thus comprises a series of timbers all from trees felled in the first half of the 11th century, but found in much later contexts, the implications of which will be further discussed below.

Mean curve 2; this curve of 167 years is calculated from the ring-widths of 6 boards from context 41-54-12, all of which probably originated in the same tree (see Fig. 3 upper and Table 6). The curve has a much lower average ring-width and mean sensitivity than curves 1 and 3 (Table 3); its less variable growth pattern is of the misleading type which appears to match in several positions, none of which can be proved with certainty. As a result the curve has not yet been dated.

Mean curve 3: this curve is based on 6 boards, probably from 4 trees, which were found in different contexts (Fig. 3 lower). Boards 41-40-12 and 43-38-11 came from the same tree, as do 43-40-9 and 43-40-10. The two boards from 41-54-12 retain most of their sapwood, suggesting felling dates some 10-15 years apart. Several other curves from this same context demonstrated very similar growth trends suggesting contemporaneity, but certain cross-matching based on year to year variations was not possible.

Several possible matches of this mean curve with mean curve 1 could not be confirmed by reference back to the individuals, and it has thus proved impossible as yet to date mean curve 3.

The remaining curves which are not included in the three mean curves consist mainly of shorter series of less than 100 years from contexts 41-54-12 and the 43-40 area. No cross-matching could be found between them or with reference data. Boards 41-54-12 B/P (from the same tree) provided a lengthy curve of over 200 years, but the extremely narrow rings could not be resolved in places. Two 17th century timbers, 39-74-2 1 and 2, produced very suitable curves but gave only inconclusive matches with reference data.

Hillam (1979a) also found at Trichay Street that two distinct groups of material were apparent - mean curve 1 closely resembles the Goldsmith Street mean curve 1 (distinguished as TS 1 and GS 1) and the Dublin chronology, while mean curve 2, based on a group of much younger timbers, is more closely linked to the German reference chronologies. The explanation again would seem to be a variety of sources for the timber.

Results on the beech boards

The three beech boards from the 43-40/42 area proved on examination to show very clear growth rings which could be measured without difficulty. The only problem noted also in Germany (Hollstein, 1973a) was the occasional extremely narrow ring, barely present, which could not be followed round on the thin boards as on a complete trunk section. The two examples here were located by reference to the other sections.
The almost identical growth patterns suggest that all three boards originated in the same tree; board widths of 8-12cm indicate a tree over 25cm in diameter and probably in excess of 100 years old. A mean curve of 76 years was calculated, the values for which are given in Table 9.

T9

Beech is not widely used as a building timber in England; Salzman (1952) records its use as laths for plaster walls and boards for fittings and arches, and several 13-14th century documents mention beech wood. As a tree, its natural distribution (Rackham, 1976) in Britain is confined to the south, although today the planting of beech is widespread. A beech plank recently examined dendrochronologically from Monkgate in Hull (Hillam, unpub) may have been imported.
Beech wood has been studied dendrochronologically in Germany where it has proved possible to establish a reference chronology back to 1684/1654 in the Spessart/Black Forest (Jazewitsch, 1953), and back to 1320 in the Saar and Moselle areas (Hollstein, 1973a). The wood had been used for roofing 'slates', as cleft boards and as piles.
The German beech was found to be suitable for cross-dating over wide geographical areas. It has a much higher mean sensitivity

than oak i.e. its growth rate is much more responsive to climatic and environmental change, and figures in Table 10 compare the Exeter beech curve to the two published German sections. The rings are wider on average and the mean sensitivity high in the Exeter sample. Mean sensitivity of oak rarely exceeds 0.25.

Partly for this reason, beech may prove difficult to cross-date by the techniques used for oak; the CROS computer program (Baillie & Pilcher, 1973) may not be suited to the high mean sensitivity. Nor is any information available on the quality of cross-matching to expect within and between regions, based on the study of modern trees.

As a result, no certain dating was possible for the Exeter mean curve, compared to the German reference data and the Hull curve; however the floating curve may be useful for comparison with further beech material from the Exeter area and its establishment has provided valuable experience in analysing this wood species and assessing its potential for the future.

Discussion

Results of tree-ring examination of the oak and beech boards from Goldsmith Street in Exeter have added further evidence to the information from Trichay Street (Hillam, 1979a) that timber was being used from a variety of sources. This is perhaps not surprising in view of Exeter's importance as a port. Timber may have been brought in from around the British coast, or carried from Western Europe. The main area of contact suggested by the pottery was France, and much of the timber could have originated as barrel staves from the import of wine. Such transport would result in considerable difficulties in cross-matching and dating the timbers from a site, as here.

The dated mean curve 1 varies in the degree of similarity with reference chronologies, compared to Trichay Street mean curve 1, so closely linked to Dublin. The GS curve matches slightly better with South-east England and Germany, but hardly at all with York (Table 8). This also suggests that construction on the two sites involved the use of boards brought from unknown sources of both primary and exploited woodland, to account for the variable growth pattern and rates.

Timber which could be absolutely dated proved to be much earlier than the contexts in which it was found - usually 11th century timber in 14-16th century contexts. Dating of pits and wells from the archaeological deposits is always difficult. Later reuse of suitable timber is a possibility, assuming a good state of preservation after several decades or even centuries. The presence of many timbers cut around AD 1040 could indicate the demolition and robbing of a major building on the site, using probably already waterlogged boards again for lining pits and wells.

Despite the dating problems, the mean curve 1 has extended the Exeter tree-ring chronology back into the 8th century by some 35 years.

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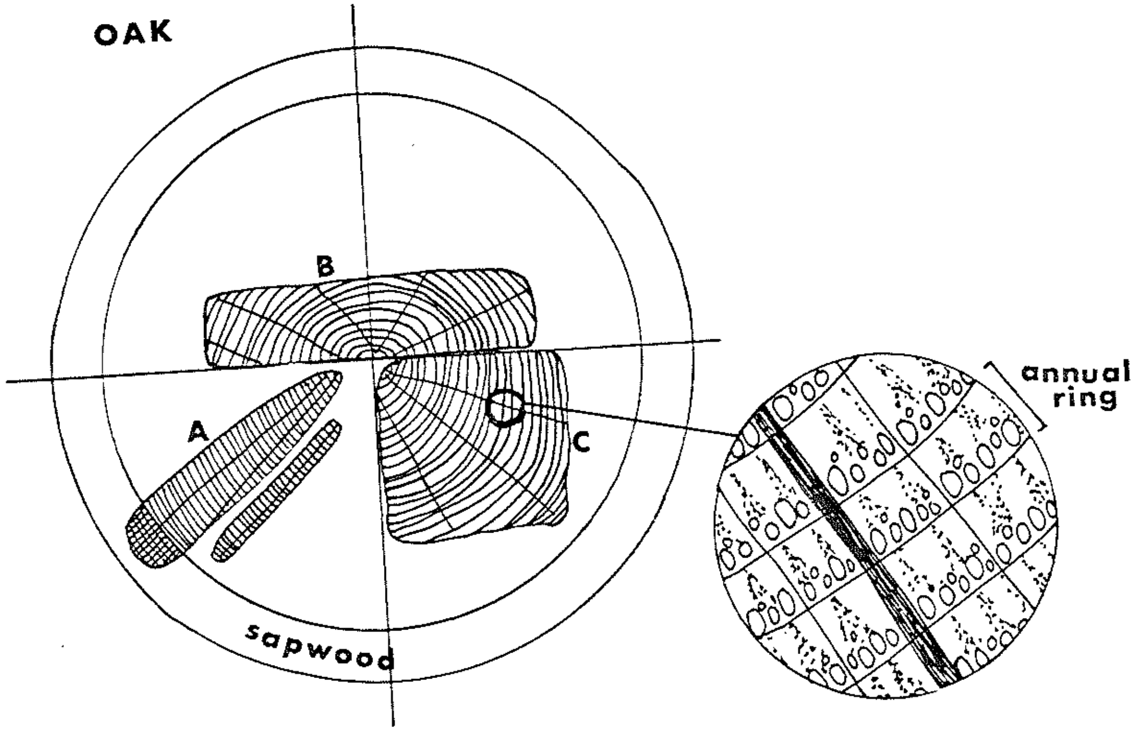
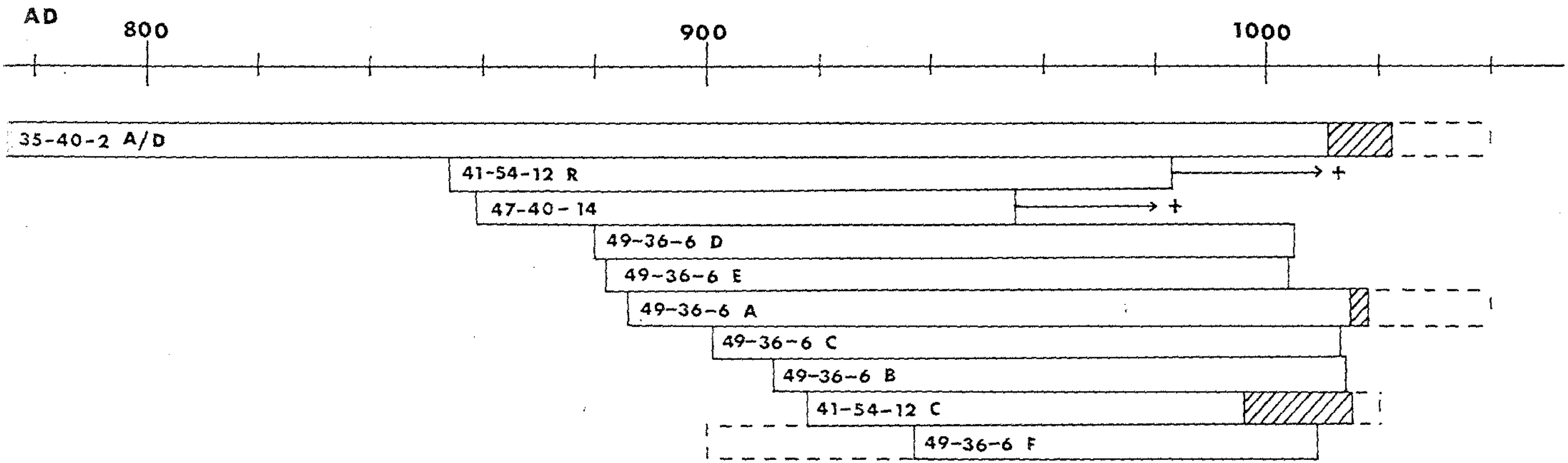
Legends to figures:

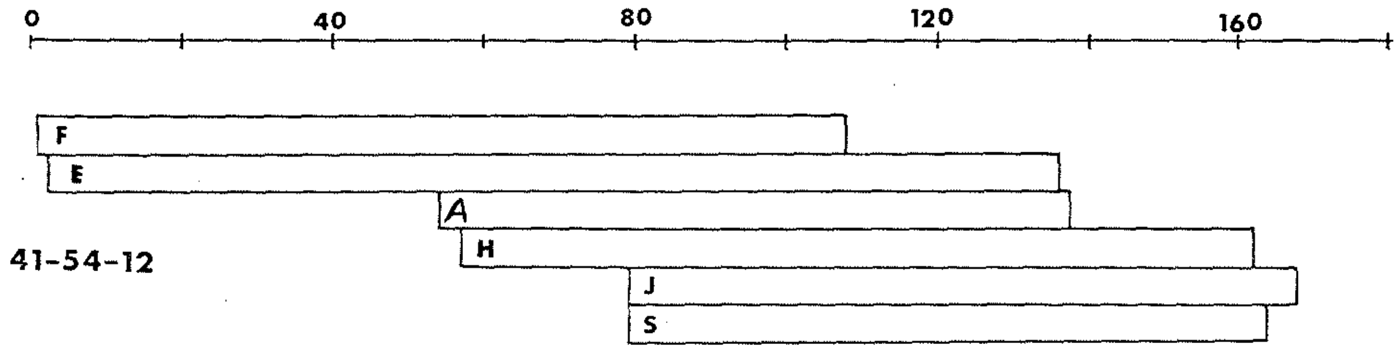
Fig. 1 Sketch diagram illustrating the microscopic structure of oak wood, with each annual ring consisting of large spring vessels and dense summer wood. The tree trunk can be cleft(or later sawn)in a number of ways, often making use of the rays (which run from pith to bark) along which natural splitting occurs. These include thin radially split boards (A), thicker tangential boards (B) or quartered trunks often used for beams (C). The outer zone of sapwood was often trimmed off, but its presence is vital to accurate dating of the tree's felling.

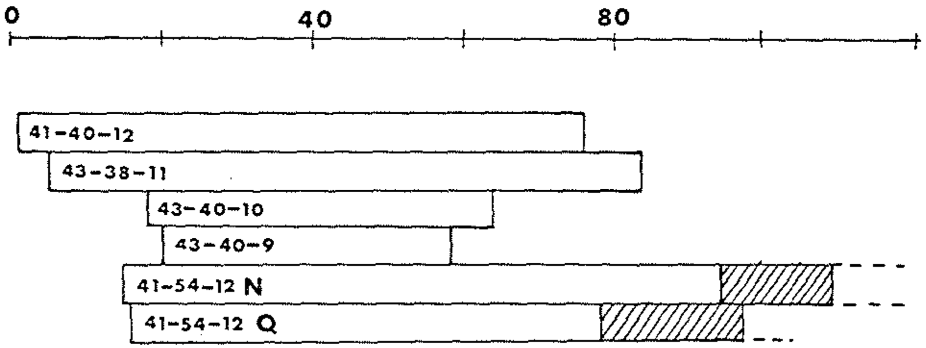
Fig. 2 Individual curves included in mean curve 1, which extends from AD 775 to 1022. Hatching indicates sapwood, dotted lines show the estimated amount of missing sapwood. Arrows and + give the earliest possible date the tree could have been felled, if no heartwood at all is missing.

Fig. 3 Individual curves included in mean curve 2 (Upper) and mean curve 3 (lower). Both curves are undated and the scale is in arbitrary years. Hatching represents sapwood, dotted lines estimated sapwood.

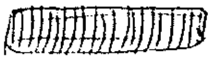
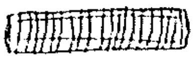
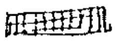
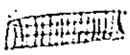
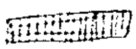
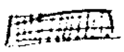

OAK
B
A
C
sapwood
annual ring

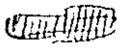
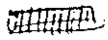
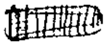
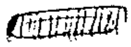
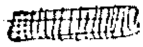
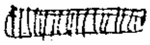
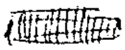
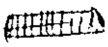
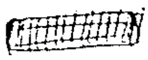

AD
800
900
1000
35-40-2 A/D
41-54-12 R
47-40-14
49-36-6 D
49-36-6 E
49-36-6 A
49-36-6 C
49-36-6 B
41-54-12 C
49-36-6 F


0
40
80
120
160
F
E
A
H
J
S
41-54-12


0
40
80
41-40-12
43-38-11
43-40-10
43-40-9
41-54-12 N
41-54-12 Q

EXETER GUILDHALL SITE; GOLDSMITH STREET

GS sample number		No. of rings	No.of sapwood rings	Ave. ring width mm	Dimensions cm	Sketch	
35-40-2	A	248	10	1.09	26.5x1.5		same tree as D
	B	60	12	2.0	9.5x9		same tree as C
	C	45	-	2.13	10x10		
	D	181	?edge	1.05	23x1		
39-74-2	1	122	-	1.73	23x2.5		same tree as 4
	2	118	-	1.97	26.5x1.5-2		same tree as 3
	3	112	-	1.91	27x0.5-2		
	4	116	-	1.68	22x2.5		
39-80-9		54	-	1.78	8.5x6 radius 10.5		
41-40-12		76	-	1.8	14x1		
41-54-12	A	84	-	0.92	7.5x1		
	B	200	-	0.71	14x2-3		
	C	98	19	1.16	12x1-1.5		
	D	69	-	1.42	10x1.5		
	E	135	-	0.91	12x1		
	F	104	-	0.81	8.5x1.5		

41-54-12 cont							
	G	46	-	1.89	8.5x1		
	H	106	-	0.86	9x1-1.5		
	J	89	-	0.91	8x1		
	K	59	-	1.87	11.5x1-1.5		
	L	71	15	1.06	7.5x1		
	M	56	-	1.75	9.5x1		
	N	95	15	1.08	10x1.5		
	P	207	-	0.7	14x1.5-2.5		
	Q	82	20	1.36	11x2-3		
	R	130	-	0.95	14.5x1		
	S	86	-	0.84	7x1		
unmeasured:		44	-		8x1		complacent
		c.53	-		12.5x1-2		
		35	-		10x1-2		wide rings
		55	-		9x1		complacent with wide rings
		34	-		9x1		
43-38-11		79	-	1.78	14x1		
unmeasured		19	-		9x2		pith with very wide rings
43-40-9	2 BEECH	76		1.59	12x0.6-.8		
	3	39	-	1.54	13x4		

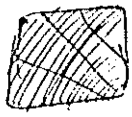
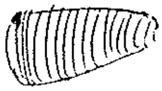
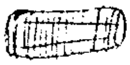
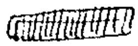
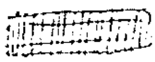
43-40-9 cont.						
unmeasured		c.35	?		8x4	
43-40-10		47	-	1.57	8x4.5	
43-40-11		58	25	1.42	14x4	
43-40-19		54	-	1.8	9x6	
43-42-7	BEECH	44		1.64	8x0.5-1.5	
43-42-8	1	72	-	0.79	5.5x2.5	
	2 BEECH	47		1.74	8x0.5-1	
	3	54	-	1.07	6x1-2	
unmeasured		c.47	-		10x10	
45-38-15 unmeasured	HAZEL	c.60			14x1-4.5	
45-42-10		63	-	0.86	5.5x2	
47-40-14		95	-	1.07	10x2	
49-36-6	A	133	3	1.3	17x1.5-3	
	B	103	-	1.12	12x1	
	C	113	-	1.25	14x3.5	
	D	126	-	1.49	19x2.5	
	E	123	-	1.46	19x2	
	F	73+	-	1.16	16x2	

Table 1. Details of all the timbers examined dendrochronologically from Goldsmith Street, Exeter.

Boards:	Extent in years/ date AD :	Average ring-width, mm:
A,E,F,H,J,S	167	0.81 - 0.92
B,P	207	0.7
C,R	AD 854 - 1005	0.95 - 1.16
D,G,K,L,M,N,Q	(46-95)	1.06 - 1.89

Table 2. The range in age and average ring-width of one group of material from context 41-54-12.

Mean curve:		Average ring-width,mm:	Mean sensitivity:
1	AD 775-1022	1.16	0.225
2		0.84	0.136
3		1.60	0.190

Table 3. Comparison of the average ring-widths and mean sensitivity for each of the Goldsmith Street mean curves.

GS sample number		no.of rings	no.of sapwood rings	years spanned AD	estimated felling date
35-40-2	A/D	248	11	775 - 1022	c.1040
41-54-12	C	98	19	918 - 1015	c.1020
	R	130	-	854 - 983	post c.1010
47-40-14		97	-	859 - 955	post c.980
49-36-6	A	133	3	886 - 1018	c.1040
	B	103	-	912 - 1014	
	C	113	-	901 - 1013	
	D	126	-	880 - 1005	
	E	123	-	882 - 1004	
	F	73+	-	(c.900)937 - 1009	

Table 4. Details of the individual boards included in Mean Curve 1 which are absolutely dated. The 6 boards from context 49-36-6 probably all came from the same tree and the estimated felling date therefore relates to them all. See also Fig. 2

		0	1	2	3	4	5	6	7	8	9	boards
AD	770						7.0	11.0	11.0	5.0	6.0	1
	780	8.0	9.0	9.0	13.0	12.0	8.0	10.0	8.0	12.0	6.0	1
	790	11.0	16.0	16.0	11.0	11.0	12.0	12.0	12.0	17.0	12.0	1
	800	13.0	10.0	14.0	10.0	12.0	13.0	11.0	9.0	15.0	13.0	1
	810	17.0	12.0	14.0	10.0	17.0	16.0	15.0	5.0	5.0	5.0	1
	820	4.0	5.0	8.0	8.0	7.0	7.0	10.0	7.0	5.0	5.0	1
	830	5.0	7.0	8.0	9.0	8.0	9.0	9.0	12.0	7.0	10.0	1
	840	8.0	7.0	9.0	10.0	10.0	16.0	10.0	10.0	8.0	9.0	1
	850	10.0	8.0	13.0	11.0	12.0	13.0	9.0	10.0	11.0	12.5	3
	860	12.5	12.0	13.0	14.0	9.0	9.5	12.5	12.0	11.0	21.5	3
	870	10.5	12.0	17.0	13.5	8.5	11.5	14.0	11.0	8.5	19.0	3
	880	16.3	18.0	12.7	18.5	14.0	14.5	19.0	20.2	21.0	12.6	6
	890	18.2	19.6	17.8	11.8	15.6	19.4	17.2	14.8	10.4	14.4	6
	900	19.2	16.8	16.2	14.5	16.0	15.5	18.3	15.3	11.7	7.8	7
	910	11.2	14.3	20.9	15.4	11.0	8.9	6.6	11.7	12.7	11.9	9
	920	11.7	11.1	12.5	13.7	14.1	16.5	13.1	16.7	11.9	13.5	9
	930	12.7	10.5	8.6	6.5	10.6	7.5	9.2	14.3	12.8	10.2	10
	940	9.1	6.4	6.0	5.7	9.9	11.4	10.9	12.9	11.6	10.2	10
	950	12.9	9.0	13.1	12.6	12.8	10.3	7.7	12.0	12.5	10.7	9
	960	11.5	12.4	7.5	9.6	7.9	7.9	9.6	10.0	13.4	12.6	9
	970	13.0	8.7	10.0	8.1	5.1	8.2	10.0	13.7	7.6	12.2	9
	980	13.6	8.4	15.2	14.5	8.2	15.2	11.6	15.2	12.5	12.2	8
	990	8.7	16.1	9.5	11.4	14.1	14.1	10.4	13.4	14.4	17.7	8
	1000	18.5	14.7	20.4	19.4	20.1	16.7	13.5	12.7	13.5	13.7	5
	1010	10.8	10.6	11.4	13.8	10.2	12.0	7.5	10.0	9.5	7.0	1
	1020	8.0	7.0	7.0								1

Table 5. Mean ring-width values (0.1mm) from A.D. 775 to 1022 for Mean Curve 1, based on 10 oak boards from the GS site. The number of boards involved in each decade is given on the right.

	0	1	2	3	4	5	6	7	8	9	Boards
0		8.0	9.0	9.0	7.0	7.5	8.5	7.5	7.5	7.0	2
10	9.0	7.5	6.5	8.5	8.0	8.0	7.5	8.0	8.5	7.5	2
20	7.5	7.0	10.0	8.0	5.5	6.0	6.5	8.5	7.5	8.5	2
30	9.0	7.5	5.5	7.0	9.0	7.0	6.0	8.0	9.5	7.5	2
40	7.0	7.5	9.5	8.5	7.0	7.0	6.5	8.0	8.5	9.0	2
50	9.0	8.0	7.5	9.0	9.0	8.3	9.7	10.2	10.2	9.7	4
60	8.2	8.7	10.2	12.2	8.5	11.0	12.0	10.0	11.0	11.5	4
70	9.5	10.2	7.5	8.5	10.5	8.7	10.2	8.7	8.2	10.0	6
80	8.3	8.0	7.8	10.0	8.5	10.8	9.3	11.0	12.2	8.8	6
90	6.7	6.8	7.2	8.0	7.8	8.0	8.3	8.7	8.2	6.8	6
100	7.8	9.7	9.5	11.3	11.7	8.6	8.4	9.2	10.4	8.0	5
110	9.2	10.6	9.6	10.0	9.8	10.4	9.0	11.6	9.8	8.4	5
120	9.4	8.6	10.4	8.6	9.4	7.0	7.4	7.8	9.2	9.2	5
130	8.0	8.8	8.8	8.2	9.0	9.8	7.2	6.2	5.3	5.7	3
140	6.0	6.0	7.0	8.0	8.3	8.3	10.3	7.3	5.7	7.7	3
150	7.0	8.3	7.0	7.3	9.7	8.0	7.0	6.7	7.7	10.0	3
160	8.0	8.3	9.0	10.5	9.0	9.0	10.0	8.0			1

Table 6 . Mean ring-width values (0.1mm) for the undated 167 year Mean Curve 2, based on 6 boards from the GS site. The boards probably all came from the same oak tree.

	0	1	2	3	4	5	6	7	8	9	boards
0		40.0	33.0	39.0	32.0	46.5	36.5	39.0	38.5	36.5	2
10	21.5	30.5	37.0	24.5	23.0	18.0	26.2	18.5	17.2	21.6	5
20	12.7	13.7	16.2	13.3	16.0	16.0	16.2	10.5	10.0	13.5	6
30	15.3	11.8	12.0	15.2	16.2	15.6	15.0	14.8	16.0	17.7	6
40	12.8	11.5	11.3	15.0	23.2	16.3	16.8	18.0	12.5	9.2	6
50	15.2	14.8	15.2	14.3	15.2	10.5	11.2	13.8	14.3	17.0	5
60	18.4	14.6	16.2	11.0	13.0	11.2	11.0	13.2	11.2	12.2	4
70	7.2	7.5	10.5	10.0	7.5	8.2	10.7	9.3	10.7	10.7	3
80	14.7	9.3	7.7	8.3	6.0	6.5	7.0	7.5	11.0	12.5	2
90	14.5	13.0	14.5	14.0	15.5	14.5	15.0	17.0	22.0	19.0	1
100	13.0	10.0	10.0	8.0	11.0	13.0	13.0	21.0	10.0	15.0	1

Table 7 . Mean ring-width values (0.1mm) for the undated 109 year Mean Curve 3 based on 6 oak boards from the GS site.

compared to:	Guildhall Goldsmith St mean 1 775-1022		Trichay St 811-1216	
	t	overlap in years	t	overlap in years
Trichay St, Exeter 811-1216 (Hillam, 1979a)	6.70	212	-	
Dublin 855-1306 (Baillie, 1977b)	5.12	168	13.12	362
Belfast 1001-present (Baillie, 1977a)	no overlap		6.49	216
Lloyds Bank Pavement ,York 778-956 (Morgan, unpub)	0.48	179	3.50	145
South-east England (REF 6) 780-1193 (Fletcher, 1977)	5.32	243	4.88	383
Germany west of Rhine (Trier) 822-present (Hollstein, 1965)	3.53	201	2.08	394
South Germany (Munich) 832-present (Huber & Giertz-Siebenlist, 1969)	2.02	191	1.68	384

Table 8 . Quality of cross-matching between the two Exeter curves, from Goldsmith St and Trichay St, and reference curves from different parts of Western Europe.

	0	1	2	3	4	5	6	7	8	9	boards
0		27.0	25.0	18.5	17.5	22.5	17.5	19.0	10.0	10.0	2
10	16.5	13.5	33.5	30.5	30.5	22.5	14.0	15.0	10.0	21.0	2
20	6.0	12.5	16.0	28.0	13.5	16.5	5.5	5.0	9.5	9.0	2
30	8.0	12.0	16.5	14.3	20.7	19.0	16.0	18.3	20.7	23.7	3
40	33.3	23.3	28.0	8.7	13.7	13.7	19.3	25.7	17.3	21.3	3
50	17.0	13.5	8.5	17.5	16.0	15.0	21.5	24.5	8.5	13.0	2
60	5.0	8.0	19.5	16.5	17.0	6.5	7.5	11.0	3.5	3.5	2
70	7.5	8.5	15.0	11.0	19.5	21.0	20.0				2

Table 9. Mean ring-width values (0.1mm) for the undated 76 year beech chronology, based on three boards from the GS site.

Curve:	Average ring-width, mm:	Mean sensitivity:
Exeter Goldsmith Street, 16th century	1.59	0.365
Germany 1320-1543	1.26	0.252
Germany 1560-1780	0.81	0.407

Table 10. Details of the Exeter beech mean curve compared to the two published sections of the German mean curve (Hollstein, 1973b and a reaspectively).

EX GS
3540 2 C
60
29 20 27 25 26 26 23 23 30 30 23 30 32 23 29 30 20 9 7 3 8 12 7 11 16
13 14 16 19 22 21 16 14 15 15 15 12 14 11 19 19 22 28 18 19 27 27 28 33 29
15 30 16 15 9 10 11 15 14 14
EX GS
3974 2-1
122
50 26 48 24 19 19 19 21 11 17 23 27 16 15 20 21 16 13 10 13 13 11 20 14 18
23 23 27 23 15 19 16 17 23 14 14 16 20 20 19 15 20 20 20 26 31 25 36 26 31
20 20 16 21 30 40 25 20 27 21 26 29 43 47 24 29 27 25 17 7 14 7 10 12 8
16 5 10 10 8 9 14 18 10 14 12 10 17 10 12 13 17 14 14 9 8 11 10 14 10
14 13 12 11 8 8 11 10 7 8 13 9 10 12 13 14 14 15 20 14 17 11
EX GS
3974 2-2
118
20 22 28 28 25 32 30 32 38 24 26 26 28 29 22 26 28 29 19 18 20 20 27 25 30
32 35 29 18 23 30 23 23 22 30 38 25 21 22 16 30 29 26 27 34 21 25 27 24 22
16 12 13 23 22 27 18 21 20 15 12 17 17 11 13 13 13 14 15 11 14 17 16 25 13
10 14 12 15 15 14 15 16 14 15 14 11 9 8 5 14 12 15 15 23 17 17 18 21 16
27 16 21 20 17 14 17 14 13 14 9 13 12 13 11 11 13 13
EX GS
3080 9
54
41 20 17 15 26 25 18 24 21 20 21 23 21 23 23 22 25 10 15 22 13 8 6 7 14
8 8 10 12 12 13 12 14 12 10 23 25 28 29 26 21 23 13 15 17 14 17 11 16 12
8 15 16 11
EX GS
4140 12
76
40 33 39 32 41 33 40 36 25 20 28 33 23 20 22 35 18 17 24 8 9 15 11 12 12
17 10 7 8 14 12 15 15 17 25 22 24 24 25 15 13 9 16 25 17 18 19 11 5 9
10 12 13 19 12 14 14 15 19 20 13 15 13 14 11 12 14 10 10 8 7 9 7 7 9
10
EXET GS
4154 120
200
16 13 12 7 13 8 11 6 8 6 5 3 5 6 6 6 6 6 13 5 9 6 5 4 6
6 4 6 6 3 4 3 4 7 7 7 6 5 4 4 4 4 4 4 5 4 7 5 6 5
5 4 5 5 5 6 3 4 4 6 4 6 8 5 6 5 5 5 5 3 4 5 6 4 5
4 5 4 3 4 4 6 5 5 4 4 4 3 5 5 4 5 9 7 8 5 5 5 6 6
7 7 6 7 12 8 8 6 9 8 11 10 8 7 6 9 10 12 12 11 10 8 6 7 5
12 11 10 12 8 14 9 11 13 12 11 10 11 9 9 9 10 7 9 7 9 6 8 7 7
7 8 8 4 5 4 5 7 8 9 6 7 7 8 7 7 7 9 8 13 5 9 8 8 8
10 8 8 8 10 10 7 10 9 9 9 8 8 10 8 10 7 6 12 10 9 7 8 8 9
EX GS
4154 120
69
33 31 26 26 27 32 32 27 37 19 33 19 21 24 11 13 10 14 12 12 18 22 22 12 14
11 8 17 15 12 15 14 16 13 13 18 18 14 8 8 10 10 15 10 11 10 9 6 6 5
5 8 12 8 11 10 10 7 8 12 5 4 5 4 5 7 10 9 6
EX GS
4154 126
46
38 26 13 22 39 35 27 23 13 24 23 20 21 21 22 20 19 16 17 23 13 11 8 19 10
13 16 14 13 18 14 16 15 18 16 27 31 15 13 14 17 17 17 13 12 11
EX GS
4154 12K
59
19 22 22 24 20 19 23 26 23 20 31 18 19 14 21 28 29 29 31 30 23 16 23 19 21
15 17 14 19 11 15 19 13 11 9 13 10 12 14 13 13 11 15 15 15 17 14 20 24 23
11 12 17 23 17 16 15 16 21
EX GS
4154 12D
71
9 8 8 13 11 11 8 9 7 5 9 7 7 9 11 12 11 10 6 12 9 9 9 8 7
7 9 6 7 7 7 6 9 12 ?? 7 11 ? ? 7 4 4 4 5 7 9 15 7 15 17
20 15 16 13 24 16 14 16 11 15 12 16 14 23 11 16 20 15 11 15 15
EX GS
4154 12H
56
12 13 11 10 19 13 18 13 15 12 15 16 18 19 14 11 13 13 13 34 22 17 21 21 22
26 21 22 17 21 25 15 10 12 17 15 12 15 13 14 17 11 21 30 15 12 13 29 17 26
20 21 13 14 15 19
EX GS
4156 12H
15
10 12 9 11 12 11 10 15 13 11 13 17 11 20 25 13 14 10 18 15 12 13 8 11 15
[illegible] 5 7 7 7 3 7 7

EX GS
4156 120
82
18 31 22 20 17 23 18 17 22 20 16 14 16 18 14 10 10 11 14 10 7 8 10 9 7
7 10 10 11 12 12 13 9 7 12 11 10 13 15 10 13 17 16 18 22 16 16 11 16 13
11 13 16 17 9 13 15 14 9 10 12 10 15 14 12 8 8 13 5 7 8 10 12 15 18
13 15 14 16 16 15 21

EX GS
4154 128
130
12 10 8 9 9 8 9 10 12 9 7 6 6 9 9 7 7 10 10 11 10 7 10 9 8
10 12 10 5 9 9 11 13 17 22 12 20 15 10 9 9 9 15 18 11 8 6 10 12 10
15 11 13 14 7 6 6 15 19 7 11 6 7 12 12 8 8 8 7 12 10 10 5 7 8
10 8 7 7 7 5 7 7 12 10 3 8 16 13 5 6 6 10 11 16 22 19 10 10 5
6 5 6 6 6 8 5 5 10 5 3 5 5 4 4 5 6 6 6 4 6 17 13 12 12
10 11 9 10 15

EX GS
4338 11
79
52 40 38 41 38 23 32 40 26 24 22 40 17 17 25 10 6 17 10 13 16 20 8 7 8
18 8 11 13 18 27 21 21 23 22 18 11 8 20 32 20 21 22 15 6 14 15 17 16 18
12 13 16 18 22 23 14 19 12 13 12 14 14 17 12 7 8 13 9 8 8 16 11 12 11
22 12 7 7

EX GS
4340 9-3
39
15 17 18 15 19 16 14 10 5 15 17 13 14 16 16 12 13 13 13 18 13 14 17 17 22
18 13 20 16 15 23 22 16 16 16 17 9 14 14

EX GS
4340 10
47
17 10 15 15 14 14 19 19 13 18 5 10 16 14 15 18 17 14 12 14 15 17 14 14 18
17 22 19 18 22 16 16 21 22 15 14 14 8 8 15 16 20 20 23 23 12 10

EX GS
4340 11
58
10 13 13 11 20 14 12 16 10 9 13 15 15 11 12 10 9 11 15 19 18 21 19 14 12
14 13 11 16 13 13 10 12 9 10 18 12 16 25 16 13 15 11 13 14 11 13 11 14 12
14 12 14 15 16 19 20 19

EX GS
4340 19
54
28 10 16 20 17 10 21 23 32 27 23 22 19 11 16 18 18 13 25 15 18 21 15 13 10
21 22 16 16 9 22 17 17 17 15 14 15 11 13 11 9 12 17 22 12 16 17 24 21 16
27 20 28 15

EX GS
4342 8-1
72
10 12 12 10 10 10 8 6 6 6 9 8 8 15 10 10 8 6 6 8 7 6 7 9 9
10 6 6 10 9 8 6 6 8 9 6 5 6 5 7 5 5 9 8 6 5 11 10 5 9
9 9 5 8 6 6 9 6 10 6 5 6 7 7 10 11 9 8 10 8 10 9

EX GS
4342 8-3
54
13 7 9 9 9 11 12 12 11 12 10 13 11 10 10 10 8 12 16 12 13 10 10 14 12
8 11 15 8 10 13 13 9 11 13 10 14 8 11 12 10 12 12 14 10 10 13 12 11 10
10 10 10 8

EX GS
4542 10
63
6 6 9 10 8 11 14 14 13 15 15 11 9 6 11 12 12 6 6 10 9 7 7 7 9
10 7 6 7 8 14 6 9 7 6 7 7 7 9 9 8 9 10 6 8 8 7 10 7 7
6 7 6 9 8 8 9 10 7 10 9 8 7

APPENDIX: RING WIDTH VALUES (0.1mm) FOR INDIVIDUAL TIMBERS FROM GOLDSMITH ST.
(SITE NAME, SAMPLE NO., NO. OF ANNUAL RINGS, RING-WIDTHS).