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TREE-RING ANALYSIS OF TIMBERS FROM NEW FRESH WHARF LONDON.

by

JENNIFER HILLAM & RUTH MORGAN

DEPARTMENT OF PREHISTORY & ARCHAEOLOGY

SHEFFIELD UNIVERSITY

Introduction

The potential of the revetment timbers in London for dendrochronological dating was first explored by Fletcher (1974) after the discovery of a substantial Roman quay of oak beams at the Custom House site (Tatton-Brown, 1974). When further river frontage sites were scheduled for redevelopment, it became possible to extend the tree-ring sampling to include other revetment structures, such as the ones found at New Fresh Wharf (Schofield & Miller, 1976) and Seal House (Schofield, 1975). The main objective of the tree-ring analysis was to provide accurate dates - either absolute or relative - for the timber structures. However, as excavations continued in the City of London, it became apparent that a vast wealth of material was available for study and that it might also yield information about the timber itself, such as how it was used and the nature of the woodland from which it originated (Hillam & Morgan, 1981a).

Excavations started at New Fresh Wharf in 1974 in Area II. No tree-ring samples were collected at this time but when a further 18m in the Area III (St Magnus) trench was excavated in 1975, a selection of timbers was sampled from the Roman and medieval levels. In 1978, the site was extended and a watching brief produced timbers of Roman, Saxon and medieval age. The analysis of the 1975 and 1978 timbers by dendrochronology provided many absolute and relative dates as well as information about the use of wood in London. Whilst the results are helpful in interpreting the archaeology of New Fresh Wharf, they will also add to

the general tree-ring research which is being carried out on timbers from many sites in the City of London.

Tree-ring analysis

Tree-ring dating is based on the measurement of the varying wide and narrow growth rings present in trees. The pattern of the annual rings can be dated absolutely by synchronisation with a tree-ring chronology which has been constructed from successively older wood samples, beginning with those from modern trees so that each ring is assigned a calender date. In England, the chief building timber was oak (Quercus sp.), chosen for its strength and durability, and it is this species which is used almost exclusively here for dating purposes.

When this study commenced in 1976, there were few dated reference curves from England, and none that extended back in time before c AD 800. In 1980, many Saxon sequences were absolutely-dated, providing a continuous English tree-ring chronology for the period AD 404-1216 (Hillam, 1981). However it was not until 1981 that the first Roman chronology from England was dated. This was achieved by correlation of the English curves with dated chronologies from Germany (Becker, unpubl.; Hollstein, 1980). The English Roman curve is continually being consolidated and extended as further timbers are examined from the City of London. At present it spans the period 252BC - AD209, so that more work is needed before samples from the later Roman period can be absolutely-dated.

Timber sampling and preparation

On site, thin sections were removed from the timbers with a chain saw, the wood being too hard, even though it was waterlogged, to warrant the use of a hand saw. At first only a random selection of timbers were sampled but recently a policy of sampling as many timbers as possible has been adopted. Ideally, every timber should be sectioned for analysis if the maximum amount of information is to be extracted. Such a policy has proved rewarding on the Continent at such sites as Hedeby (Eckstein, 1981).

The wood samples from 1975 were kept under water at the DoE's Ancient Monuments Laboratory prior to their transport to Sheffield. Subsequent samples were stored at the DUA, sealed in polythene, until ready to be sent to Sheffield. (A Dymo-tape label inside the bag, plus a finds label on the outside, has proved to be the most reliable and convenient method of labelling.) Since 1978, two samples per timber have been removed, one of which is sent for tree-ring analysis whilst the other remains at the DUA against the event of it being needed for C14-dating or for further research. The samples taken are 5-15cm thick; anything thicker is unmanageable in the laboratory, as well as causing storage problems. Once in the dendrochronology laboratory, some of the larger timbers - for example, the massive sill-beams from the Roman revetment - had to be reduced in cross-section to a thin segment with a chisel, since the original beams would not have fitted under a microscope.

The waterlogged samples were frozen overnight before being surfaced with a plane (Stanley surform) to expose the structure of the growth rings. The ring widths of the 1975 samples were measured with a 10X hand lens, containing a 0.1mm scale. Later samples were measured, under a low-power binocular microscope, on a travelling stage connected electronically to a display panel, which reveals the ring widths after each annual ring has been traversed.

The ring width data were plotted on transparent semi-logarithmic recorder paper. The ring patterns were synchronised by sliding one graph over and past another until the position of best fit was found. Computer programs were also used to save time and to give an objective measure for the agreement between two curves. Early tree-ring matching relied upon a program written in Hamburg (Eckstein & Bauch, 1969), but the later work was aided solely by the Belfast computer program (Baillie & Pilcher, 1973), which proved to be far more useful (Hillam, 1979). The former program outputs the results as % agreement values (W), whilst the latter calculates Student's t-value for each position of overlap between two curves. A value greater than $t = 3.50$ is significant, provided that it is accompanied by an acceptable visual match.

PERIOD 1: ROMAN TIMBERS

The Roman quay in Area III (Fig.1), excavated in 1975 (Schofield & Miller, 1976), consisted of ground piles and cradling timbers which supported massive sill-beams. Built up on these were a series of horizontal beams,

probably to a height of five or more beams. They were held in place by tieback braces and piles. Pairs of piles were in position immediately behind the sill-beams at the west end of Area III. Thirteen timbers were sampled, providing wood sections from a variety of components from the structure (Table 1). They were provisionally dated to the 2nd century AD, based on the extensive pottery finds.

In January 1978, the original site was extended when the contractors again began work. The watching brief produced little stratified pottery so that the phasing and the dating of the new site was based on that from the controlled excavation. Fifteen timbers were sampled for tree-ring analysis (Table 1). As well as four samples from the Roman quay, partly excavated in 1975, five sections were taken from timbers belonging to the Roman revetment for land reclamation. This was thought either to be contemporary with the quay or to pre-date it. Finally, six piles from the foundations of the Roman riverside wall were sampled. Timbers from this wall had already been examined from the Baynards Castle site at Blackfriars (Hill et al, 1980) and the Tower of London (Parnell, 1978).

Phase 4: The Roman quay

The thirteen timbers from the 1975 excavation had between 49 and 218 growth rings and all appeared suitable for measurement and crossdating. Some or all of the sapwood was preserved on seven. The 1978 timbers contained 115-202 rings, but none of the sapwood remained.

The timbers selected for sampling had served several functions (Table 1, Fig.1): seven had been sill-

beams (SM 205, SM 311, SM 378, FRE 5002, FRE 5003, FRE 5013 and FRE 5014) and were large, rectangular-shaped timbers. Sometimes the complete trunk had been hewn into a rectangle (eg SM 378), but others had been shaped from halved (eg FRE 5003) or quartered trunks (eg FRE 5014); this no doubt depended upon the size of the available trunks after felling. Of similar type were beams from the second (SM 236) and third (SM 243) rows above the sill-beams. The cradling timber (SM 321) was a quartered trunk. Three piles (SM 190, SM 212 and SM 213), standing in pairs behind the sill-beam, were squared complete trunks with fewer and wider rings, as were the two braces (SM 326 and SM 386). Finally, a stray piece (SM 279) and a timber of unknown function (SM 322) were again squared trunks.

The majority of the samples had rings of narrow to average width, suggesting that the trees had grown in a woodland where they were subject to competition from other trees. The woodland source was obviously a stand with trees of different ages and sizes, since some timbers derived from mature oaks whilst other trees must have been felled when young. Some of the mature trees must have been massive: SM 311 had a cross-section of 74 x 37cm, indicating that the tree was at least 90cm in diameter. It would have been about 250 years of age when felled and must have involved a considerable effort in felling, transport and conversion. The youger trees, less than 100 years old when felled, had diameters of 40-50cm, allowing for missing sapwood. These tended to be wider-ringed and were presumably selected because of their greater

strength, due to the larger proportion of dense latewood. As such, they were used for piling and bracing.

Nine of the St Magnus ring patterns (tree-ring curves) crossmatched, with t-values of up to 9.96, to form a site mean curve of 262 years (Fig.2). This was combined with data from the Custom House and Seal House sites and published as a Roman London mean curve (Morgan & Schofield, 1978). When the four Roman quay timbers from the 1978 watching brief were examined, two of these synchronised with the original 262-year curve (t = 3.70 and 7.46 for FRE 5003 and FRE 5014 respectively). For the purpose of this report, a new site chronology was produced (Table 2). This includes the data from the nine 1975 timbers, the two 1978 timbers and FRE 677 (see below).

Of the unmatched samples, four were from young trees (SM 190, SM 212, SM 213 and SM 243) and two from older ones (FRE 5002 and FRE 5013). Short ring patterns are sometimes difficult to crossmatch, but in this case some other factor must be involved as SM 326, with only 49 rings, did crossdate. Tentative matches were found for the St Magnus samples but none were sufficiently convincing to warrant publication. A sample from SM 213 was radiocarbon-dated: it gave a result of ad 320±70 (HAR-1421). The two 1978 samples matched each other (t = 5.66), but not even a tentative match was found between them and the synchronous New Fresh Wharf curves. A series of three C14 samples, taken at known intervals of time from FRE 5013, were submitted for analysis to determine if they differed in date. The temporary results were not conclusive as they indicated a felling date between ad 15±120 and ad

395±90 (Table 3). More will be said about the C14 results, when the dating of the Roman structures is discussed below.

Why FRE 5002 and FRE 5013 do not crossdate, when their ring patterns seem ideally suited to tree-ring dating, is not known. Possible reasons are that these timbers were re-used or that the trees from which they were hewn came from another woodland, where different conditions of growth prevailed. The C14 result for SM 213 is consistent with the felling dates of the matching timbers (see below), indicating that the second possibility is more likely, at least for the unmatched St Magnus timbers.

An estimate of the felling dates of trees used to construct the quay can be made by examining the amounts of sapwood on the timbers as this maintains a fairly standard width, calculated as 20-40 rings in mature oak trees (for further discussion, see Hillam, 1979). SM 378 has a wide zone of 38 rings (Plate 1), SM 321 (Plate 2) and SM 279 have around 20 rings and SM 386 has 4 rings. The approximate felling times are given in Table 4. A '+' denotes those timbers for which an unknown amount of missing heartwood has to be allowed, ie the value is an estimate of the terminus post quem. Such timbers are assumed to have contemporary felling dates. The figures generally indicate a felling date around the arbitrary years 265-270. Construction would have followed very soon after felling as it was not the Roman practice to season timber (Hollstein, 1965). The quay was therefore also constructed in arbitrary years 265-270. The absolute dating is discussed in a later section (see below).

Phase 3: The Roman revetment for land reclamation

Five timbers were sampled from this structure (Table 1): FRE 677 was a large timber, with 217 growth rings, and of similar size to some of the sill-beams from the Roman quay. The others (FRE 368, FRE 369, FRE 680 and FRE 681) were smaller timbers containing between 37 and 79 rings. FRE 677 was a quartered trunk which had been hewn into rectangular shape. The tree would have been c 250 years old when felled and have had a diameter of at least 1m, whilst the remaining samples came from trees, younger than 100 years old, with diameters ranging from c 30-60cm. As with the Roman quay, the woodland source contained oaks of varying size and age. The average widths of the annual rings were similar to those of the Roman quay timbers.

When the ring widths had been measured, the data from FRE 368 was rejected since the 37-year ring sequence was too short to be crossmatched with any reliability. The other curves were compared with the Roman quay sequences. FRE 677 crossmatched well at the position indicated in Figure 2. The quality of the agreement between it and the other New Fresh Wharf curves (t = 9.97) suggested that the timbers had come from the same woodland. FRE 369, FRE 680 and FRE 681 did not match, either with the Roman quay curves or with each other.

FRE 677 had 4 sapwood rings and the date of its heartwood-sapwood boundary was roughly similar to that for SM 378, ie year 240 on the arbitray scale. It is there-fore probable that it was felled and used for construction

at the same time as the Roman quay timbers. If the revetment did pre-date the quay, it could only be by 10 years. Since FRE 677, which derived from a mature oak tree, could easily have had c 45 sapwood rings, it seems more likely that the two structures were contemporary.

Dating the Phase 3 and 4 timbers

When the first New Fresh Wharf timbers were examined, there were no dated British tree-ring chronologies with which to compare their ring patterns. Several short sequences from Europe had been published (eg Hollstein, 1972, 1974), and one of these curves, Wederath (Hollstein, 1972), gave a tentative match (t = 4.08) when the 262-year London curve ended in AD 151 (actually AD 178; for the revised dating see Hollstein, 1980). While this agreed with the archaeological dating, the visual match was poor and comparisons with Hollstein's most recent curve (1980) did not confirm the result. Absolute dating was finally achieved in 1981, but not before approximate dates had been obtained by other methods.

1. Radiocarbon dating

With the failure to obtain absolute dating, four radiocarbon samples, each covering 20 rings, were cut from beams SM 311, SM 378 and SM 321 at 50 year intervals with respect to the mean curve. The full details are given in Table 5. The results show considerable variability but, with growth allowance added to account for missing heart-

wood and sapwood, the felling date averages out at ad 295±35 (R. Otlet, pers.comm.). Since this date did not agree with the late 2nd century date suggested by the pottery sequence, further radiocarbon samples were taken from the Custom House timbers, which were firmly dated dendrochronologically in relation to the New Fresh Wharf timbers (see below and Fig. 3). The three Custom House radiocarbon results were earlier than those from New Fresh Wharf: when related to arbitrary year 270, the estimated felling date for the New Fresh Wharf timbers, they gave an average value of c ad 215 (Table 5). The variability of the radiocarbon results obtained here suggests that radiocarbon dating should be used only to give a rough indication of a sample's date and not as a means of acquiring an exact date. It is valueless, for example, to compare the dates in Table 5 with those of the unmatched timbers, FRE 5002/5013 and SM 213. The results are so variable that no constructive comment can be made about their relative dating.

2. Relative dating and archaeological evidence

When the 1975 Phase 4 samples were examined, timbers from two other riverside sites in London were available for comparison: Seal House and Custom House, upstream from New Fresh Wharf by 200m and 500m respectively. The New Fresh Wharf and Seal House tree-ring curves crossmatched well with a t-value of 9.96 (Fig. 2 in Morgan, 1977). The estimated felling dates of the timbers (Fig. 3) indicated that the two structures were contemporary, whilst the quality of the agreement between

the ring sequences suggested that the timbers had come from the same woodland (Morgan, 1977; Morgan & Schofield, 1978), ie the New Fresh Wharf and Seal House excavations had exposed parts of the same structure. Also synchronous were the Custom House curves, measured by Fletcher (1974), although an exact felling date could not be given for the Custom House revetment since no sapwood had been preserved. An estimate of the terminus post quem indicated that the Custom House structure had been built no more than c 80 years before that at New Fresh Wharf and Seal House (Fig. 3).

Roman timbers from other sites in the City were examined in 1980 and 1981, and several tree-ring chronologies produced which crossmatched with New Fresh Wharf. The temporal relationship of the various master curves is set out in Figure 3, whilst examples of the crossmatching are illustrated in Figure 4. Twelve revetment timbers from the Thames Street Tunnel site, excavated in 1978, had matching ring sequences, resulting in the production of a 198-year master curve, whilst the 1978 Watling Court excavation uncovered oak piles, four of which were used to construct the 167-year master curve. These two sequences synchronised well with each other, with New Fresh Wharf/Seal House, and with a well timber from the 1976 Milk Street excavation (Table 6). In 1981, over 40 timbers from the 1979 Peninsular House excavation were analysed. The majority of the ring sequences cross-matched and twenty were incorporated into the 322-year master curve. The crossdating of these sequences from

London meant that accurate relative dating was possible. In addition, evidence of the Hadrianic Fire at Watling Court indicated that the oak piles from that site were felled in c AD 100 (C. Harding, pers.comm.). This made it possible to assign approximate calender dates to the tree-ring chronologies and to their respective felling years. Using this time scale, the Phase 3 and 4 timbers from New Fresh Wharf were felled and used for construction in c AD 230-40.

3. Absolute dating

By 1980, two unpublished chronologies were available: one from Ireland, spanning 12BC - AD894 (Baillie, 1980), and the other, 397BC - AD216, from the Danube region of southern Germany (B. Becker, pers.comm.). No crossdating was found between London and Ireland, but a tentative match was obtained between the Danube curve and London's Thames Street Tunnel (t = 3.99 when the last ring of TST was equal to AD 39).

In early 1981, the data of Hollstein's West German oak chronology (700BC to the present day: Hollstein, 1980) was obtained. Simultaneously, work on the Peninsular House timbers had resulted in the production of a new London tree-ring chronology. All the Roman London sequences were therefore compared with the two German chronologies. The tentative Thames Street Tunnel/Danube match was confirmed as the Thames Street Tunnel curve matched with Hollstein's chronology over the same period of time. Peninsular House also matched well with both curves.

The t-values were highly significant at the $P < 0.001$ level (Table 6) and the visual agreements were good. Calender dates could therefore be given to all the relatively-dated London curves (Hillam & Morgan, 1981b). The 262-year New Fresh Wharf sequence spans the years 53BC - AD209, and the Phase 3 and 4 timbers were felled in AD 212-217 (Table 4).

Phase 8: The Roman riverside wall

The 1978 watching brief revealed a section of the Roman defensive wall with its oak pile foundations. No associated pottery was found by which to date it, but the structure was similar to the sections of wall already excavated at Baynard's Castle, Blackfriars (Hill et al, 1980) and the Tower of London (Parnell, 1978), where tree-ring work had been carried out on the oak timbers. (A description of the wall as found at Baynard's Castle and Upper Thames Street is given in Hill et al, 1980.) At Blackfriars, a mean curve of 116 years was produced. No absolute dating was possible because of the lack of dated reference curves for the Roman period, but a series of four radiocarbon dates indicated that the timbers were felled around ad 330-50 (Morgan, 1980). The Tower of London excavation produced six piles for tree-ring analysis. Three of these crossmatched, both with each other and with the Blackfriars master curve. The relative positions of the ring sequences from the two sites suggested that the two sections of wall were part of the same structure. However, there was evidence from the estimated felling dates of the individual timbers, that the wood had been cut at different

times and either stockpiled or re-used (Hillam & Morgan, 1979).

The removal of six oak piles from Phase 8 at New Fresh Wharf made it possible to compare further ring patterns with those from the two sites described above. The samples (FRE 374-9) contained between 41 and 64 growth rings (Table 1). They came from whole trunks which had been hewn into rectangular shape, and were roughly similar in size and shape to the piles found at Blackfriars and the Tower. The average widths of the annual rings were also similar at the three sites (c 2mm).

The New Fresh Wharf ring patterns proved difficult to crossmatch, as had those from the Tower, due to the shortness of the ring sequences. Four curves were synchronised visually, although some of the agreements were not statistically very significant (t = 2.90-5.53). After the production of a site master curve, the other two samples were also crossmatched (Fig. 5). In view of the poor quality of some of the matching, a final master curve was not produced but instead, the ring patterns were compared individually with the Blackfriars master curve. (The ring width data of the samples can be found, together with those from all the other New Fresh Wharf timbers, at the end of this report.) Four Phase 8 samples gave high t-values (4.03-5.87) with Blackfriars, and all six ring patterns showed good visual agreements at the positions indicated in Figure 5 (see also Fig. 6 for an example of this). When the Phase 8 master curve, made up from the four original matching patterns, was tested against

Blackfriars, it agreed less well than the individual curves, so justifying the decision not to present a finalised master curve. The quality of the agreements between Blackfriars and the individual New Fresh Wharf curves suggested that the timbers were brought from the same woodland. Examination of the estimated felling dates, however, indicated that the timber for the six piles could not have been felled in the same year (Fig. 5). This was in agreement with the findings at the other two sites, and indicated the stockpiling or re-use of timber prior to the construction of the wall at the three sites (see Hillam & Morgan, 1979, for further discussion).

It was estimated that 750 piles were required for the foundations of the c 40m section of wall, excavated at Blackfriars (Hill, 1977). The construction of the one mile stretch of wall from Blackfriars to the Tower would therefore involve a vast number of piles if all the unstable ground was to be consolidated, and would suggest a large scale exploitation of the surrounding woodland. If there was pressure to complete the wall as quickly as possible, re-used or stockpiled timber may have been needed. Such a theory would explain why the usual Roman practice of building with green timber did not occur here (see Hollstein, 1965).

Some of the New Fresh Wharf timbers had been felled later than those from Blackfriars, for example FRE 375 had a felling date at year 144 or after on the arbitrary scale (Fig. 5). Since the radiocarbon date of

c ad 330-50 for the felling date of the Blackfriars timbers was estimated with respect to year 120 on the arbitrary scale, the most likely date for the construction of the riverside wall, taking into account the tree-ring results from all three sites, is c ad 350-70.[1]

The Phase 8 ring sequences are therefore too young to overlap with the absolutely-dated Phase 3 and 4 ring curves, and indeed no such such match was found. None of the riverside wall curves from the three sites appear to crossmatch with Hollstein's dated German chronology, whilst the Danube chronology does not cover this period. In time however it should be possible to link the riverside wall curves with absolutely-dated chronologies and so obtain a more accurate result.

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[1] Further work at the Tower of London indicated that the wall was probably constructed within the last decade of the 4th century AD (G. Parnell, pers.comm.). The radiocarbon results are consistent with this date.

PERIOD 2 AND 3: SAXON AND MEDIEVAL TIMBERS

Significant Saxon features were found in Area II (New Fresh Wharf, 1974), Area III (St Magnus, 1975) and in the area covered by the 1978 watching brief. The remains of many timbers were uncovered, some of which were sampled for tree-ring analysis. Much of the material had less than 50 growth rings and was not sent to Sheffield. Of the timbers which were examined, some were dated relatively and others absolutely.

Early medieval features were discovered above those of the Saxon period (Miller, 1977). Several timber structures were excavated, such as those associated with the first, second and third early medieval embankments, some of which produced samples for tree-ring work. A list of all the Saxon and medieval timbers, examined at Sheffield, can be found in Table 7.

PERIOD 2

Phase 2

Although many timbers were found in Area III during the 1975 excavation, none were sent for tree-ring analysis. These timbers were from the first Saxon embankment, dated by radiocarbon to ad 870±60 (Miller, 1977). In 1978, other timbers from the embankment were excavated and one of the stakes (FRE 4001A) was sectioned. The timber contained 55 growth rings, twenty of which were from the sapwood zone. Its ring pattern crossmatched with some of those from the Period 3 timbers and, because of the presence of sapwood, it

was therefore dated with some accuracy in relation to the ring sequences from timbers associated with the second Saxon embankment (see below and Fig.7).

PERIOD 3

Phase 1

Six 10th century timbers were sampled in 1975, four of which had enough rings to merit measurement (SM 7, SM 130, SM 183 and SM 273). In 1978, eight sections were removed from timbers associated with the second Saxon embankment. Six of these were from stakes and rough timbers belonging to an early property boundary at the side of the second Saxon embankment (FRE 3003, FRE 3004A, FRE 3005B, FRE 3006A, FRE 3008A and FRE 3009A), whilst the remaining two were from random timbers located within the embankment (FRE 575A, FRE 575B).

When the 1975 timbers were examined, some tentative crossdating was found. SM 183 appeared to agree well with REF 6 (Fletcher, 1977), when its rings were assigned the years AD 858-1023. Although the agreement gave a t-value of 5.13, later work proved that this match was not correct.

Of the six property boundary timbers, FRE 3009A had only 40 annual rings (Table 7) and was not included for measurement. The other ring patterns were compared, one against the other, and all but FRE 3005B were found to crossmatch (Fig.7). The ring sequence of FRE 4001A, the Period 2 timber, also synchronised

with this group, so providing relative dating for the first Saxon embankment and the timbers associated with the second embankment.

A mean curve of 149 years was produced from the five matching ring patterns (Table 8). Although it was compared with all available reference chronologies from the Saxon and early medieval periods, no convincing crossdating was found. However, sapwood and the heartwood-sapwood boundary were present on FRE 4001A and FRE 3004A respectively. It was therefore possible to determine that timber FRE 4001A was felled in c year 127 and FRE 3004A in c year 181 on the arbitrary scale (Fig. 7). The first Saxon embankment, containing stake FRE 4001A, was thus constructed c 54 years before the timbers of the property boundary were felled and used for demarcation. If the property boundary and the adjacent second Saxon embankment were contemporary, it follows that c 54 years elapsed between the construction of the first and second embankments.

Absolute dating was provided for the property boundary timbers when the ring pattern of FRE 3005B was correlated with other New Fresh Wharf tree-ring sequences (Figs 8,9). It gave t-values of 4.24 and 5.99 with FRE 592 and SM 183 respectively (for an explanation of the dating of these timbers, see below), when its outer ring was AD 968 (Table 9). It had no sapwood so that an accurate felling date could not be calculated. However, the timber must have been felled after AD 991.

An explanation as to why the other property boundary timbers will not date cannot yet be given. Obviously they were not growing under the same conditions as FRE 3005B or their ring patterns would be similar. However, assuming

that the property boundary timbers were felled at the same time, it can be postulated that the boundary was marked out some time after AD 991 and that the first Saxon embankment was constructed c 54 years before that.

Further evidence for the dating of the second embankment comes from timbers FRE 575A and FRE 575B. Their rings cover the periods AD 875-932 and AD 866-944 respectively (Fig. 8). FRE 575A was felled after AD 955 and FRE 575B after AD 967. This is consistent with the later 10th century date suggested above. Finally, SM 183 was dated to AD 767-932, with a felling date after AD 955, by comparison with a ring sequence from Tudor Street, London (Hillam, 1981). The ring pattern also matched well with that of FRE 592 (see below). The t-values were 5.00 and 6.64 respectively. Although SM 183 has previously been tentatively crossmatched at a different date, there was no doubt that the second match was correct (Fig. 9). Its date therefore was also consistent with those obtained above.

Phase 2

The three phase 2 timbers were excavated in 1978. FRE 595 and FRE 597 were timbers from the revetting tip in the first early medieval embankment, whilst FRE 3001 was found on the surface of the embankment. The data from FRE 595 was rejected because the timber had less than 50 growth rings. FRE 597 and FRE 3001 had 76 and 89 rings respectively. No crossmatching was found for FRE 3001, but FRE 597 agreed well with several dated chronologies when its outer ring was equal to AD 1045 (Table 9, Fig. 8). The agreement values (t) were 3.59 with Seal House (Morgan, forthcoming), 3.66 with

REF 6 (Fletcher, 1977), 4.21 with the Munich chronology (Huber & Giertz-Siebenlist, 1969) and 4.23 with the German chronology for west of the Rhine (Hollstein, 1965). (Many of the Seal House tree-ring curves were also dated by comparison with German chronologies - see Morgan, forthcoming.) The terminus post quem for the felling of FRE 597 is AD 1068, indicating that the revetting tip of the first early medieval embankment must have been constructed some time after this date.

Phase 4

Two timbers (SM 98, SM 112) of postulated 12th century date were excavated in 1975. They proved to be very wide-ringed and had few rings (Table 7). No measurements were made of their ring widths.

The three 1978 timbers sampled for dendrochronology consisted of a post (FRE 8004) from an early medieval embankment, probably the second, and two random timbers (FRE 576, FRE 592) which had possibly been used in the revetting tip lines of the second embankment. The ring pattern of FRE 8004 was dated to AD 1045-1159 by comparison with curves from Seal House (t = 5.91) and the Munich area of Germany (t = 3.88). The visual match between FRE 8004 and Seal House is illustrated in Fig. 10. The timber had 3 sapwood rings so that the felling date of the timber was calculated as AD 1188±9 (allowing for 32±9 rings of sapwood - see Baillie, 1973, and Hillam, 1979).

FRE 576 and FRE 592 were also dated (Table 9, Fig. 8). FRE 576 crossmatched with Seal House (t = 5.16) and the Dublin chronology (t = 3.16; Baillie, 1977). The

timber was felled after AD 1097, suggesting that it was earlier in date than FRE 8004. FRE 592 was even earlier: its rings covered the period AD 835-961, indicating that it was felled after AD 984. (Neither FRE 576 nor FRE 592 had any sapwood.) It crossmatched with other New Fresh Wharf sequences (see above and Fig. 9) and with chronologies from various regions of the British Isles. The t-values were 4.32 with REF 6 (Fletcher, 1977), 3.33 with Dublin (Baillie, 1977), 3.72 with Exeter (Hillam, 1980), 3.81 with Tudor Street, London (Hillam, 1981), and 3.89 with a ring sequence from Lloyd's Bank site, York. There was therefore no doubt about the dating of FRE 592. As with other sites in London, the timbers from New Fresh Wharf had ring patterns which were similar to those found in many parts of the British Isles and also in Germany (for further discussion, see Hillam & Herbert, 1980).

The felling date of FRE 592 (after AD 984) is comparable to those obtained for timbers associated with the second Saxon embankment. It may have originally been used in that, or in a contemporary structure, before being re-used in the 11th or 12th centuries. Other evidence for the re-use of timber was found during the 1975 excavation (Miller, 1977).

Phase 5

In 1978, two timbers were sampled from the third medieval embankment. FRE 543 had 70 growth rings and FRE 10001 had more than 100 very wide rings (Table 7). No matching was found for these ring patterns.

Phase ?

A timber of 13th-14th century date (SM 141) was

sectioned during the 1975 excavation. Unfortunately, it had only 26 very wide growth rings and so could not be used for tree-ring analysis.

The Saxon and medieval timber

As only a few timbers were sampled from each phase, it is difficult to draw any firm conclusions. However, a few generalisations can be made until future work provides more substantial evidence. The Saxon and medieval timbers were of poorer quality than the Roman ones. The only timber which was comparable in size to the massive Roman sill-beams was FRE 10001, and that did not compare in quality. This might suggest that the supply of large timbers was diminishing due to continuing exploitation of the woodlands. The fact that the Saxon and medieval trees were felled at a much younger age supports this theory: none of the trees could have been older than 200 years of age when felled. The Saxon timbers in particular were small, rather knotty and taken from young trees. The presence of double-centres in three of the samples (Table 7 - for example, FRE 3005B) indicates that the wood came from a trunk which was beginning to branch, ie from a less suitable part of the tree than the main trunk.

However, since good quality timber from mature oaks was available in medieval London, such as some of the radially-split beams found at Seal House (Hillam & Morgan, 1981a; Morgan, forthcoming), supplies could not be very limiting. They would not be as plentiful as in Roman times, and the Saxon and medieval property owners were probably less willing to waste valuable timber on waterfront structures when more inferior timbers would be just as adequate for the task.

Conclusion

Tree-ring analysis at New Fresh Wharf has provided absolute dating for the Roman, Saxon and medieval periods. The results are totally reliable, but their accuracy depends upon sapwood rings, the presence of which are necessary if an accurate felling date is to be estimated.

For the Roman period, relative dating indicated that the quay and the revetment for land reclamation were constructed within a few years of each other, if not at the same time. Absolute dating then provided a calender date of c AD 214 for this construction time. The use of radiocarbon dating was found to be very limited as an aid to accurate dating, although it is useful to give a rough guide to a sample's age.

The ring sequences of the 4th century timbers from the defensive riverside wall are still floating in time but they are linked relatively to timbers from other stretches of the wall at Blackfriars and the Tower of London. In time the chronology will be dated absolutely but until then historical evidence suggests that the wall was constructed within the last decade of the 4th century.

Many of the Saxon and medieval ring patterns were dated although, for reasons unknown, some still remain undated. The use of tree-ring dating indicated that some of the medieval timbers were re-used from late Saxon times. The use of re-used or stockpiled timber was also prevelant in the 4th century, as was shown by the work on the riverside wall timbers, although the usual Roman practice was to use green timber.

Finally, information about the timbers themselves: their size, age, method of conversion, has been collected. It is obvious that better quality timbers were used in the Roman period but further deductions cannot be made at this stage. The data however will be added to that already collected from other sites in the City of London, and will form the basic framework for future work.

New Fresh Wharf illustrates the usefulness of tree-ring analysis, both as a dating method and as a source of information about the past use of timber. The main lesson to be learned from the study is that sampling should be more extensive if the full potential of dendrochronology is to be realised: ideally every timber should be sampled.

Acknowledgements

The authors are grateful to the Ancient Monuments Branch of the DoE for financing the work.

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LEGENDS TO FIGURES

Figure 1: Axonometric plan of the Roman quay, excavated in Area III (St Magnus, 1975), identifying those timbers with matching tree-ring curves (in brown) and those which were sampled but not matched (in blue).

Figure 2: Bar diagram indicating the years spanned by the ring sequences of the matching Phase 3 and 4 timbers. SM - timbers excavated in 1975; FRE - those excavated in 1978. Sapwood rings are represented by hatching.

Figure 3: Temporal relationship of the ring sequences from the various Roman London sites. Arrows represent approximate felling dates; '+' indicates an estimation of the terminus post quem. CUS'73 - Custom House; MLK'76 - Milk Street; PEN'79 - Peninsular House; SH'74 - Seal House; SM'75 and FRE'78 - New Fresh Wharf; TST'78 - Thames Street Tunnel; WAT'78 - Watling Court.

Figure 4: Matching site master curves: New Fresh Wharf/Seal House (NFW), Thames Street Tunnel (TST) and Watling Court (WAT), over the period 73BC - AD57.

Figure 5: Bar diagram illustrating the years spanned by the ring sequences of the Phase 8 timbers, and their relationship to the mean curves from the other two river-side wall sites. Arrows represent approximate felling dates with a '+' indicating the calculation of the terminus post quem. (a) - felling date of the earliest timber from each site; (b) - felling date of the latest timber; H/S - heartwood/sapwood boundary.

Legends to figures (cont)...

Figure 6: Matching tree-ring curves: FRE 379 and FRE 378 with a section of the Blackfriars master curve (BC).

Figure 7: Bar diagram indicating the years spanned by the ring sequences of the floating Saxon master curve. Arrows - estimated felling dates; H/S - heartwood/sapwood boundary; hatching - sapwood rings. The scale in years is an arbitrary one.

Figure 8: Bar diagram illustrating the relative positions of the Period 3 ring sequences, and their relationship to two other London tree-ring chronologies. Arrows - felling dates (with the exception of FRE 8004, all are terminus post quem estimates); hatching - sapwood rings.

Figure 9: Examples of crossmatching ring patterns for the period AD 850-950.

Figure 10: The dating of FRE 8004, AD 1045-1159. The agreement between it and Seal House (Morgan, forthcoming) gave a t-value of 5.91.

+ 2 plates

LEGENDS TO TABLES

Table 1: Details of the Roman timbers. The cross-sectional sketches are not drawn to scale. Asterisk - sample not measured.

Table 2: New Fresh Wharf master curve for the Roman period, 53BC - AD209.

Table 3 : Results of radiocarbon analyses carried out on the unmatched FRE 5013. The growth allowance must be added to the C14 result so that the three samples relate to the same felling date, that is, year 161 on the scale of the FRE 5013/5002 mean curve.

Table 4: Relative and absolute dating of the Phase 3 and 4 timbers. A '+' by the felling date indicates that an estimate of the terminus post quem has been made.

Table 5: Radiocarbon results for samples from New Fresh Wharf and Custom House, the ring patterns of which are included in site master curves. The exact relationship, in years, between each sample is known from the tree-ring analysis. The results can therefore all be related to the estimated felling date of the New Fresh Wharf timbers (year 270 on the arbitrary scale) by the addition of the appropriate growth allowance.

Table 6: t-values for the agreements between the various Roman London site master curves, and between them and the two dated German chronologies. Site codes are explained in the legend to Fig. 3.

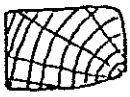
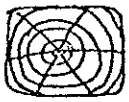
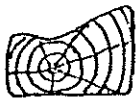
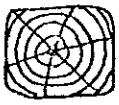
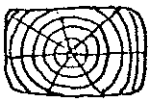
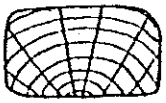
Legends to Tables (cont).....

Table 7: Details of the Saxon and medieval timbers. The sketches of the cross-sections are not to scale. Asterisks - samples not measured.

Table 8: Ring width data of the floating Saxon master curve; samples included are FRE 3003, FRE 3004A, FRE 3006A, FRE 3008A and FRE 4001A.

Table 9: Details of the dating of the Saxon and medieval timbers; all samples are from the 1978 watching brief (FRE), except for 183 (SM).

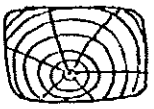
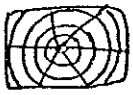
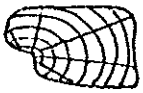
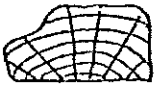
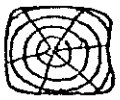
Appendix: Ring-width data of all measured samples from New Fresh Wharf. The first line identifies the sample, the second states the number of rings per sample, and the third and subsequent lines give the ring widths in 0.1mm.

no.	function	no. of rings	sapwood rings	average width(mm)	dimensions (cm)	sketch
Period 1, phase 3						
* FRE 368		37	-	2.72	20 x 15	
FRE 369		68	-	1.73	18 x 11	
FRE 677		217	4	1.61	39 x 29	
FRE 680		79	14	1.85	25 x 19	
FRE 681		57	-	2.18	20 x 15	
Period 1, phase 4						
SM 190	pile	51	-	4.25	31 x 30	
SM 205	sill-beam	134	-	2.80	45 x 34	
SM 212	pile	62	11	3.25	30 x 29	
SM 213	pile	70	8	2.74	23 x 23	
SM 236	second row beam	197	-	1.63	60 x 38	
SM 243	third row beam	80	23	2.86	38 x 26	
SM 279	stray	92	19	2.43	28 x 24	
SM 311	sill-beam	218	-	1.88	74 x 37	

(Table 1)

cont.....

.....cont (Table 1)

no.	function	no. of rings	sapwood rings	average width(mm)	dimensions (cm)	sketch
SM 321	cradling beam	163	20	1.64	31 x 30	
SM 322	unknown	111	-	1.80	29 x 24	
SM 326	third row tieback brace	49	-	1.76	26 x 23	
SM 378	sill-beam	212	38	1.76	59 x 38	
SM 386	third row tieback brace	61	4	2.16	23 x 16	
FRE 5002	sill-beam	115	-	2.78	35 x 28	
FRE 5003	sill-beam	152	-	2.08	56 x 31	
FRE 5013	sill-beam	125	-	2.03	52 x 30	
FRE 5014	sill-beam	202	-	1.78	37 x 32	
<u>Period 1, phase 8</u>						
FRE 374	pile	41	-	2.80	22 x 12	
FRE 375	pile	64	-	2.01	21 x 17	
FRE 376	pile	58	-	1.90	21 x 18	
FRE 377	pile	62	1	1.82	22 x 16	
FRE 378	pile	48	-	2.05	21 x 14	
FRE 379	pile	47	-	2.14	17 x 13	

year	ring widths (0.1mm)										number of samples
	0	1	2	3	4	5	6	7	8	9	
0		13.0	18.0	18.0	24.0	28.0	32.0	19.0	34.5	33.0	1
10	29.5	26.0	26.5	23.0	28.0	31.5	34.5	26.5	31.5	30.0	2
20	23.3	28.0	30.7	38.7	34.7	33.0	26.0	43.0	36.5	37.4	4
30	33.6	29.2	24.0	19.0	17.4	23.2	24.2	33.4	25.2	27.8	5
40	30.8	24.4	22.4	20.8	29.4	25.2	20.0	23.2	24.0	22.8	5
50	25.3	18.3	16.5	12.8	19.3	22.0	20.8	19.2	20.3	22.8	6
60	20.2	18.8	24.0	19.5	15.2	15.0	14.8	15.0	19.8	20.7	6
70	21.0	19.5	18.8	19.8	13.3	11.0	9.5	19.1	18.7	22.4	6
80	23.4	19.7	25.4	15.6	17.1	14.7	15.9	14.3	17.7	15.6	7
90	18.4	26.0	19.2	18.9	22.1	17.6	18.0	23.2	21.0	18.1	8
100	17.5	20.1	23.4	17.0	19.1	23.9	23.5	25.7	22.5	22.0	8
110	18.2	19.6	17.4	19.1	22.4	18.5	20.9	21.1	18.4	21.0	8
120	23.0	23.7	27.2	23.2	23.5	17.7	14.0	23.1	18.4	19.3	9
130	15.6	18.8	19.2	16.7	18.4	16.1	13.0	13.7	13.1	18.0	9
140	23.3	20.4	18.1	19.4	19.0	15.7	14.4	11.8	19.0	16.9	9
150	18.6	12.2	14.1	16.0	18.9	17.2	13.8	14.3	16.1	15.0	9
160	15.4	17.8	17.9	19.3	18.9	21.1	18.4	14.7	11.8	14.6	9
170	21.2	21.7	22.4	24.6	18.9	19.5	17.7	20.3	14.8	20.1	10
180	20.4	22.1	17.9	20.1	19.7	20.7	19.7	21.6	21.8	23.5	10
190	19.5	15.9	20.3	18.8	20.5	22.5	19.6	21.2	19.5	13.0	11
200	18.3	19.1	16.5	22.1	21.9	19.2	17.9	12.2	20.2	17.3	10
210	15.2	16.0	15.1	16.2	19.4	19.0	17.2	17.4	14.7	15.4	9
220	18.2	17.3	18.6	16.6	17.0	17.8	14.6	20.2	19.0	22.8	7
230	15.8	19.0	16.2	16.5	13.2	15.5	17.0	16.5	18.2	16.0	4
240	16.5	18.2	15.2	16.7	11.7	10.5	12.0	13.0	13.5	16.0	4
250	16.7	15.0	11.7	11.7	13.7	13.7	13.0	9.0	10.3	13.7	3
260	16.3	11.0	13.0								2

Table 2

HAR no.	rings of 161-year mean curve	growth allowance (years)	temp. C14 result	felling date (ad)
3104	27-46	125	ad 270±90	395±90
3105	57-76	95	ad 30±100	125±100
3103	87-106	65	50±120bc	15±120

Table 3

sample no.	no. of rings	sapwood rings	years spanned (arbitrary scale in brackets)	felling date
Phase 3				
FRE 677	217	4	46BC - 171AD (8-224)	207-212 AD (260-5)
Phase 4				
FRE 5014	202	-	35BC - 167AD (19-220)	197AD+ (250+)
FRE 5003	152	-	29BC - 123AD (25-176)	153AD+ (206+)
SM 311	218	-	53BC - 165AD (1-218)	195AD+ (248+)
SM 236	197	-	25BC - 172AD (29-225)	202AD+ (255+)
SM 378	212	38	5BC - 207AD (49-260)	207-212 AD (260-5)
SM 205	134	-	24 - 157AD (77-210)	187AD+ (240+)
SM 322	111	-	37 - 147AD (90-200)	172AD+ (225+)
SM 321	136	20	74 - 209AD (127-262)	212-217 AD (265-70)
SM 279	92	19	117 - 208AD (170-261)	212-217 AD (265-70)
SM 326	49	-	130 - 178AD (183-231)	202AD+ (255+)
SM 386	61	4	132 - 192AD (185-245)	212-217 AD (265-70)

Table 4

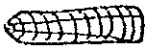
HAR no.	rings of 270-year mean curve	growth allowance (years)	C14 result	result related to NFW felling date
NEW FRESH WHARF				
1867	70-90	190	ad 110±60	ad 300±60
1865	120-140	140	ad 150±60	ad 290±60
1864	170-190	90	ad 290±60	ad 380±60
1868	220-240	40	ad 190±60	ad 230±60
CUSTOM HOUSE				
2532	40-60	220	70±70 bc	ad 150±70
2530	70-90	190	ad 80±70	ad 270±70
2534	115-135	145	ad 80±70	ad 225±70

Table 5

	WAT	MLK	TST	NFW/SH	Danube	W. Germany
PEN	10.80	-	15.61	6.61	3.95	3.85
WAT		4.02	10.56	5.48	2.85	1.62
MLK			4.98	2.20	-	2.26
TST				6.02	3.99	3.12

Table 6

Table 7

	no.	function	no. of rings	sapwood rings	average width(mm)	dimensions (cm)	sketch
	Period 2, phase 2						
	FRE 4001A	stake	55	20	1.25	18 x 17	
	Period 3, phase 1						
	SM 7		73	2	1.65	radius 12	
*	SM 14		39	-	wide	radius 10	
	SM 130		62	-	3.39	21 x 2	
*	SM 172		-	?	narrow	radius 9	
	SM 183	board	166	-	1.51	27 x 6	
	SM 273		75	10	3.21	28 x 25	
	FRE 3003	stakes, rough timbers	76	-	1.94	23 x 16	
	FRE 3004A		56	1	1.70	19 x 19	
	FRE 3005B		100	-	2.12	32 x 22	
	FRE 3006A		120	-	1.89	25 x 18	
	FRE 3008A		103	-	1.51	28 x 26	
*	FRE 3009A		40	11	2.44	20 x 16	
	FRE 575A	random timbers	58	-	2.60	24 x 16	
	FRE 575B		79	-	1.62	23 x 23	
	Period 3, phase 2						
*	FRE 595		44	-	3.07	29 x 8	
	FRE 597		76	-	1.81	34 x 13	
	FRE 3001		89	-	1.48	32 x 8	

cont.....

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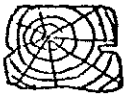
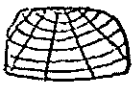
no.	function	no. of rings	sapwood rings	average width(mm)	dimensions (cm)	sketch
Period 3, phase 4						
FRE 576	random timbers	58	-	2.26	27 x 14	
FRE 592		127	-	1.35	27 x 9	
FRE 8004	post	115	3	1.83	37 x 33	
* SM 98		c 50	c15	wide	25 x 3	
* SM 112		c 35	-	wide	17 x 7	
Period 3, phase 5						
FRE 543		70	-	2.71	31 x 27	
FRE 10001		102+	-	wide	75 x 28	
Period , phase						
* SM 141		26	6	wide	19 x 10	

Table 7

year	ring widths (0.1mm)										no. of samples
	0	1	2	3	4	5	6	7	8	9	
0		18.0	20.0	12.0	9.0	5.0	6.0	13.0	9.0	12.0	1
10	19.0	17.0	12.0	8.0	8.0	10.0	6.0	5.0	5.0	8.0	1
20	16.0	24.0	16.0	10.0	13.0	24.0	21.0	13.0	21.0	20.0	1
30	10.0	17.0	14.0	13.0	11.0	13.0	12.0	16.0	11.0	20.0	1
40	16.0	20.0	15.5	15.0	18.0	14.0	12.0	19.0	10.5	10.5	2
50	11.5	16.5	12.5	13.5	18.0	19.5	17.7	15.0	27.7	23.7	3
60	21.7	28.3	19.2	19.2	23.7	17.7	18.5	15.7	18.0	14.2	4
70	21.5	17.0	12.7	17.5	14.2	16.2	13.2	12.2	12.5	11.5	4
80	12.5	14.5	8.2	14.7	14.0	23.7	22.5	22.0	18.5	23.0	4
90	17.7	11.0	12.5	9.5	10.4	13.4	17.6	18.4	17.8	23.4	5
100	20.0	12.8	18.4	18.8	13.6	12.8	14.6	19.4	17.4	15.6	5
110	16.4	18.7	20.5	17.7	22.0	21.0	25.0	20.5	26.5	23.2	4
120	16.2	16.7	20.0	18.3	19.7	22.0	19.7	17.7	21.7	19.0	3
130	17.3	15.3	16.7	14.3	14.0	15.7	17.7	20.3	20.0	18.5	3
140	14.5	18.5	15.5	20.0	21.0	19.0	26.0	13.0	17.0	12.0	1

no.	type of dating	date range	felling date
Period 2, phase 2			
4001A	relative (see Fig.6)		
Period 3, phase 1			
3003	relative		
3004A	"		
3005B	absolute	AD 869-968	after AD 991
3006A	relative		
3008A	"		
575A	absolute	AD 875-932	after AD 955
575B	"	AD 866-944	after AD 967
183(SM)	"	AD 767-932	after AD 955
Period 3, phase 2			
597	absolute	AD 970-1045	after AD 1068
Period 3, phase 4			
576	absolute	AD 1004-1074	after AD 1097
592	"	AD 835-961	after AD 984
8004	"	AD 1045-1159	AD 1188±9

NEW FRESH WHARF

AREA III

ROMAN WATERFRONT

AXONOMETRIC

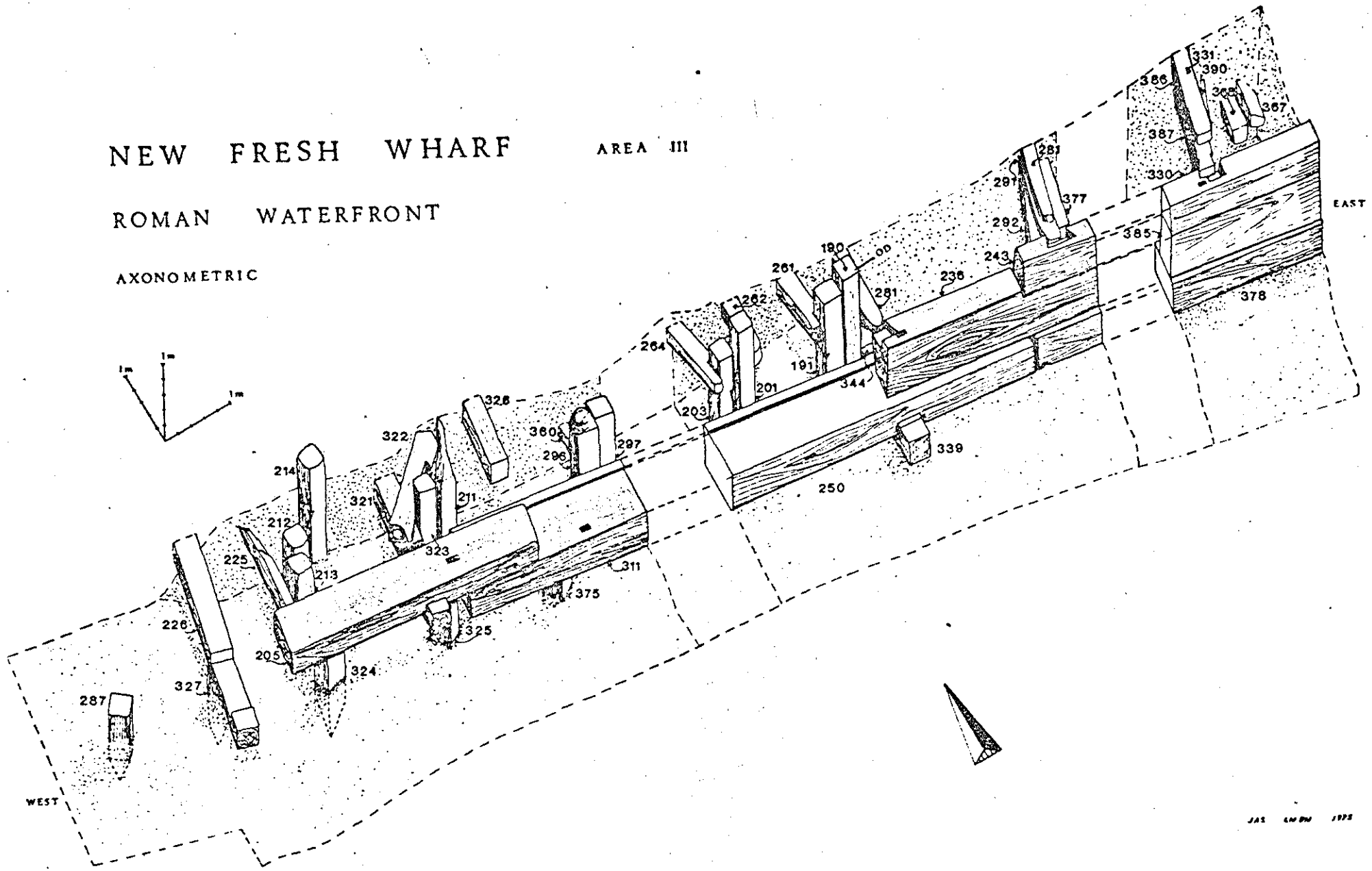
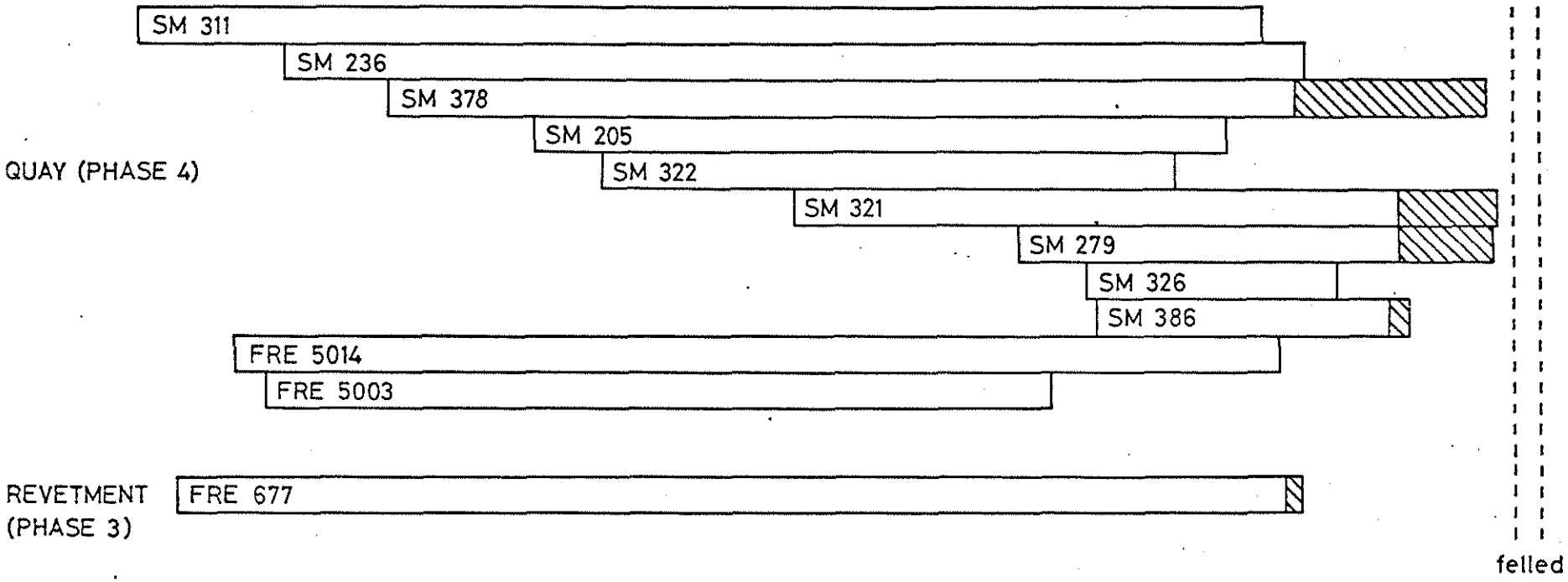


Fig 1


SM 311
SM 236
SM 378
SM 205
QUAY (PHASE 4)
SM 322
SM 321
SM 279
SM 326
SM 386
FRE 5014
FRE 5003
REVETMENT
(PHASE 3)
FRE 677
felled


arbitrary years: calender
0
50
100
150
200
250
50
BC 11 AD
50
100
150
200

FIG 2

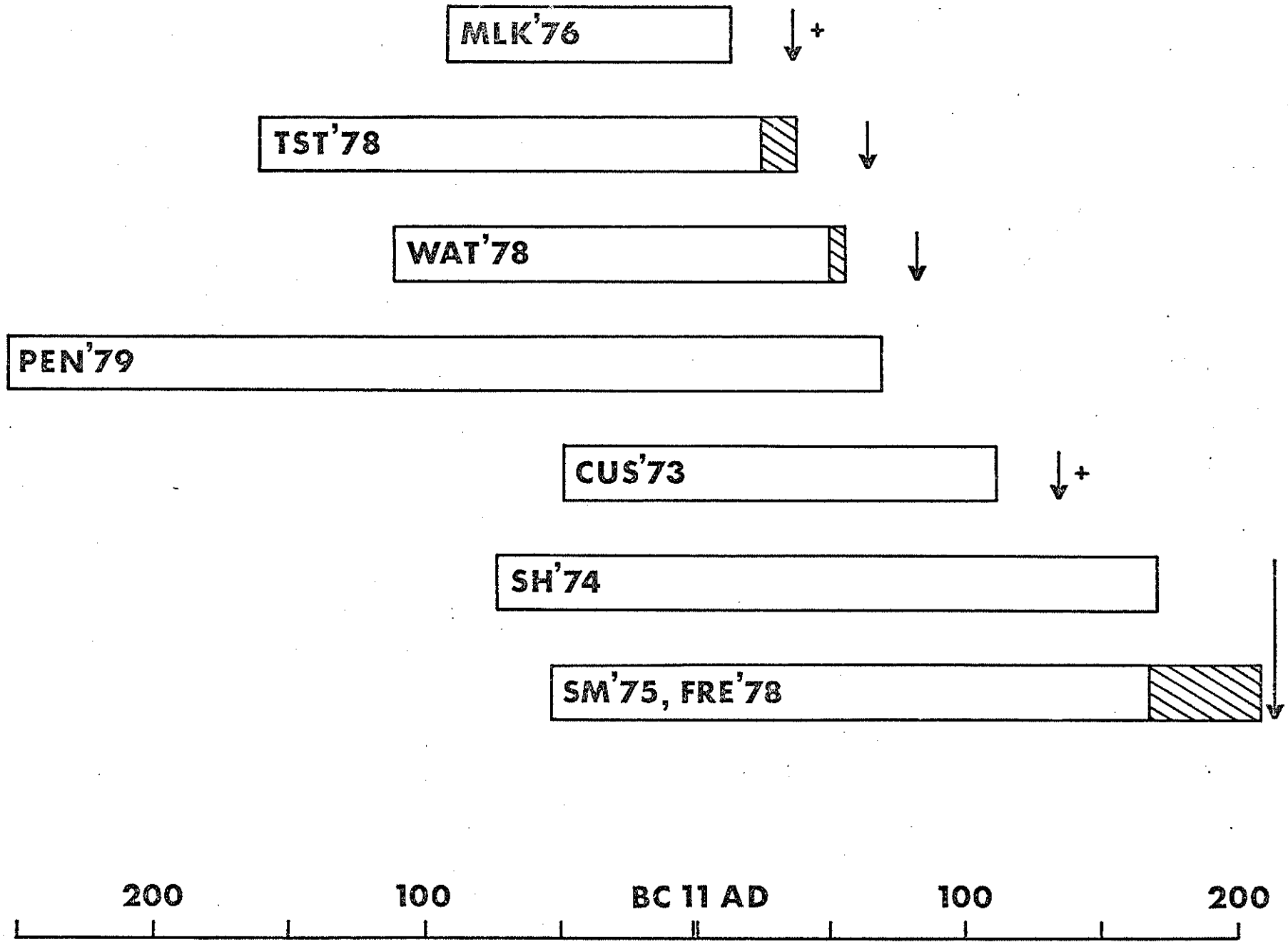

MLK'76
TST'78
WAT'78
PEN'79
CUS'73
SH'74
SM'75, FRE'78
200
100
BC 11 AD
100
200

FIG 3

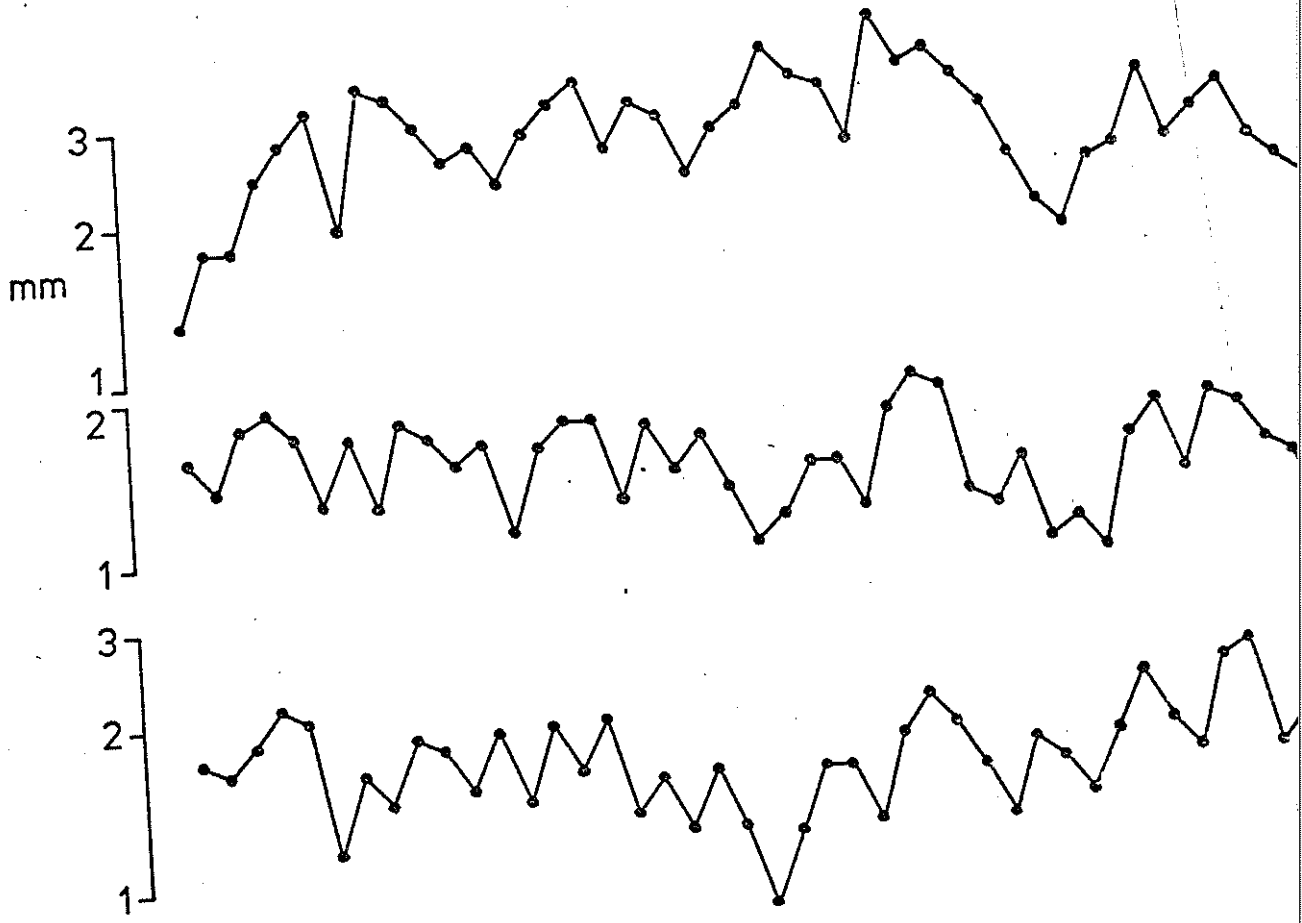
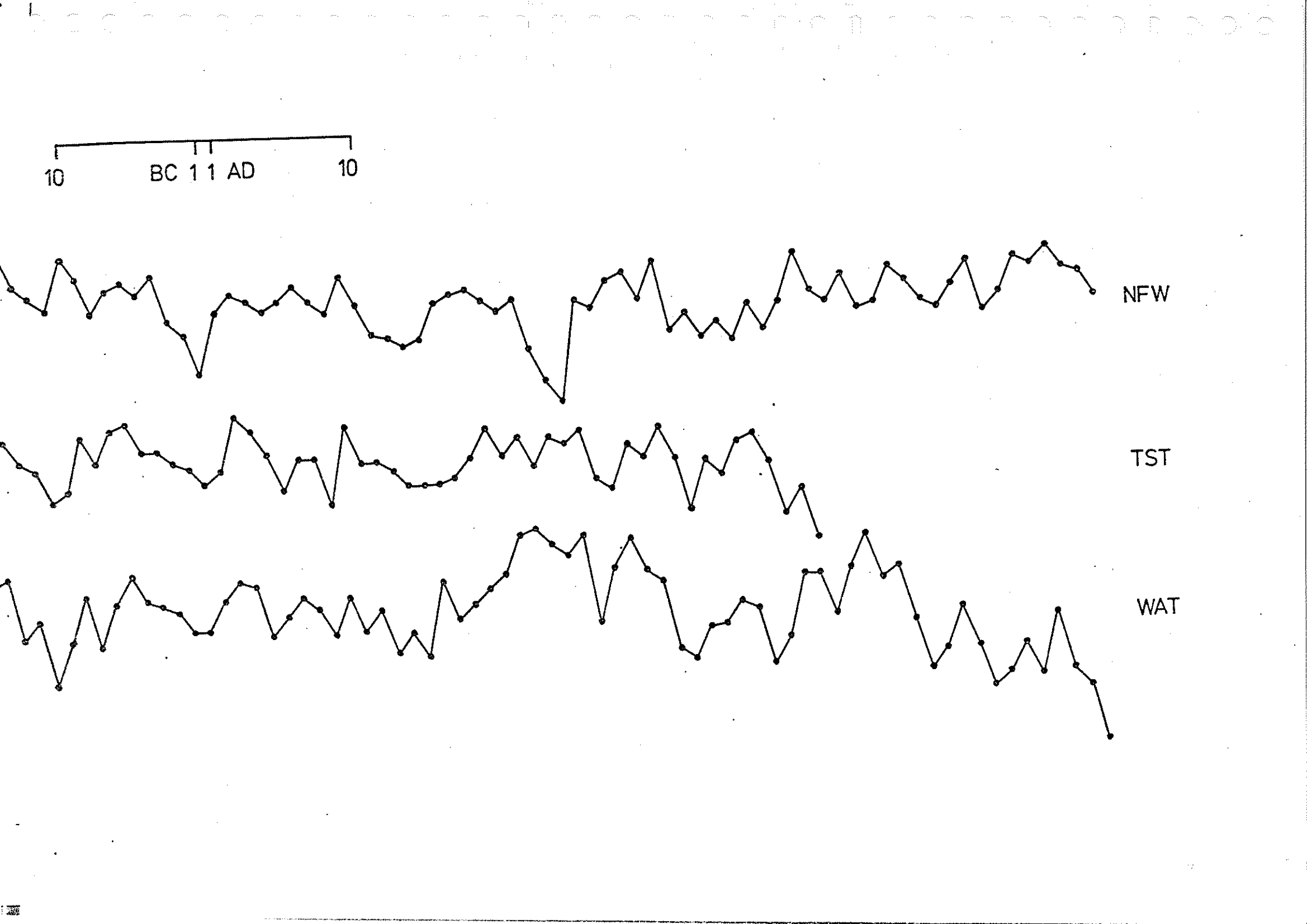
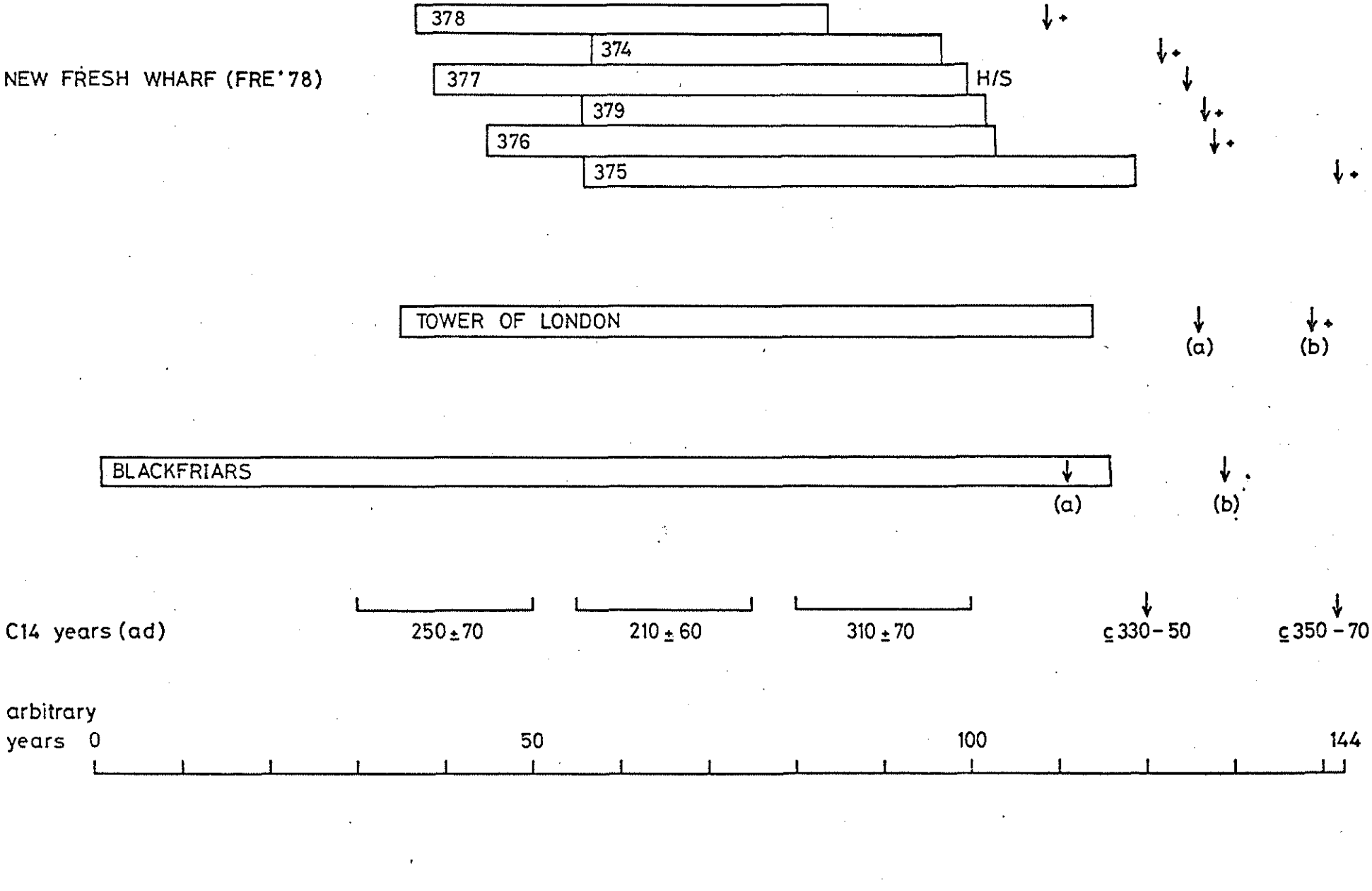


FIG. 4


10
BC 1 1 AD
10
NFW
TST
WAT


NEW FRESH WHARF (FRE'78)
378
374
377
H/S
379
376
375
TOWER OF LONDON
(a)
(b)
BLACKFRIARS
(a)
(b)
C14 years (ad)
250 ± 70
210 ± 60
310 ± 70
c 330 – 50
c 350 – 70
arbitrary
years 0
50
100
144

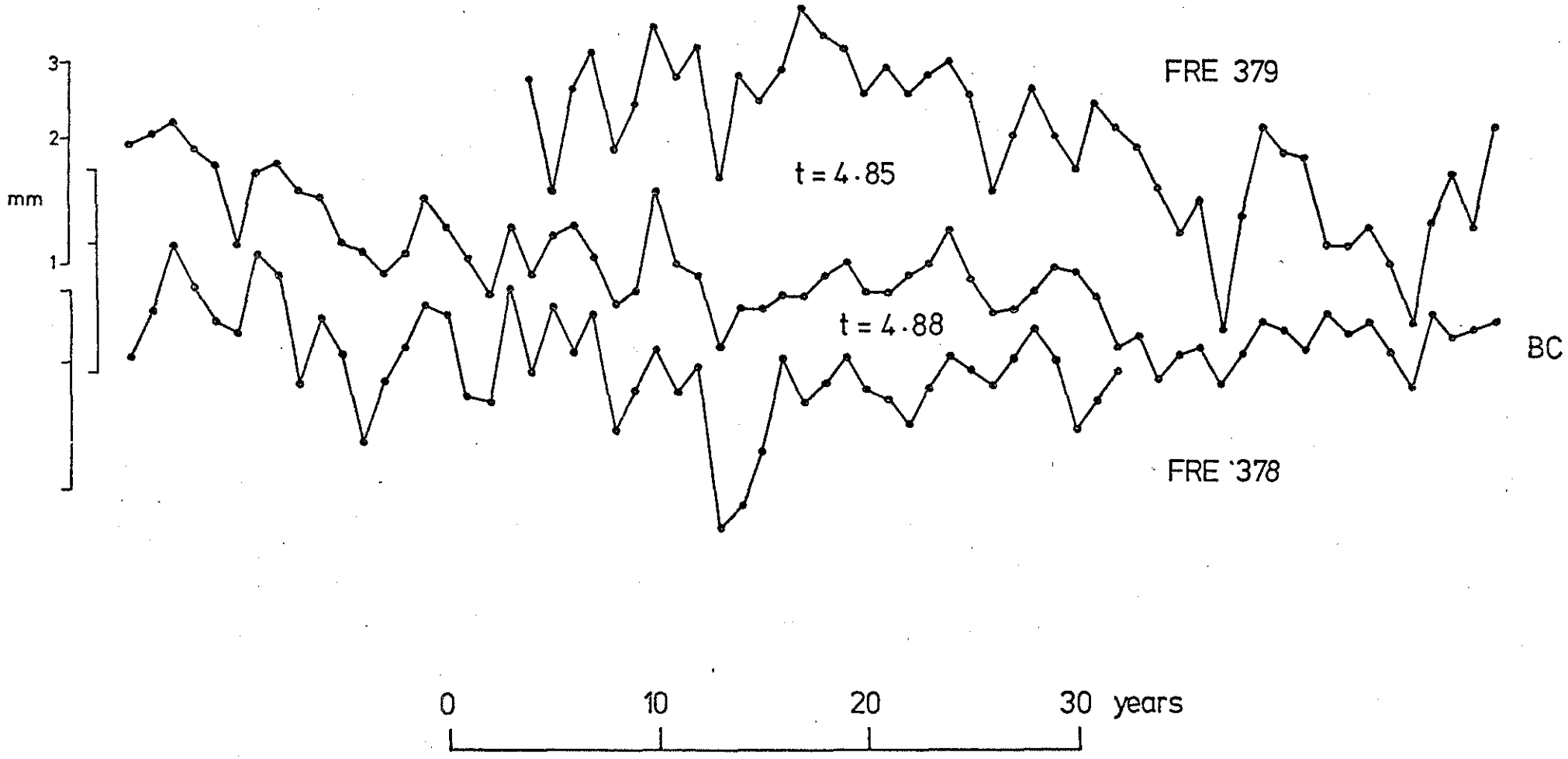
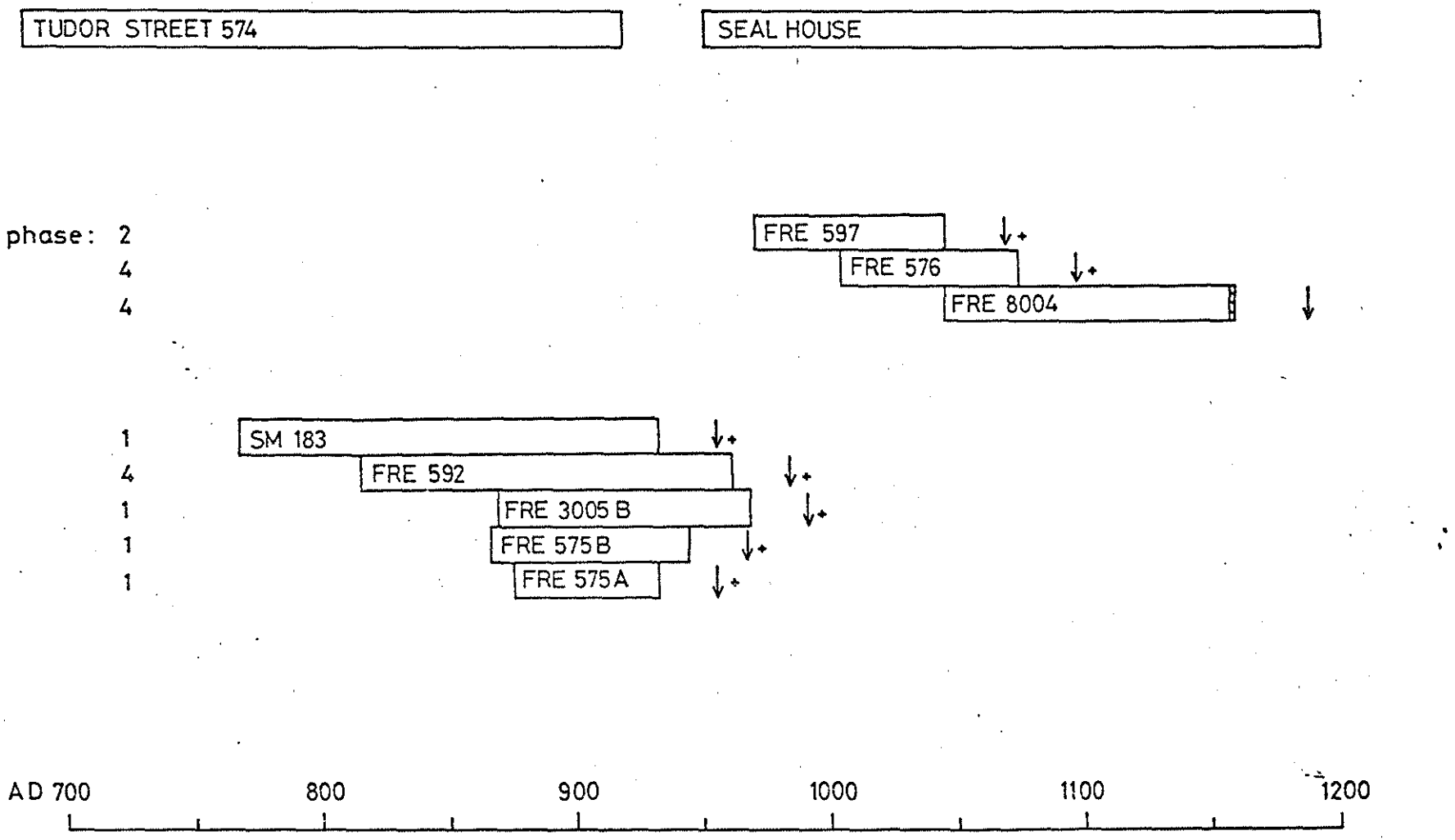


FIG. 6

FIG.8


TUDOR STREET 574
SEAL HOUSE
phase: 2
4
4
FRE 597
FRE 576
FRE 8004
1
4
1
1
1
SM 183
FRE 592
FRE 3005 B
FRE 575 B
FRE 575 A
AD 700
800
900
1000
1100
1200

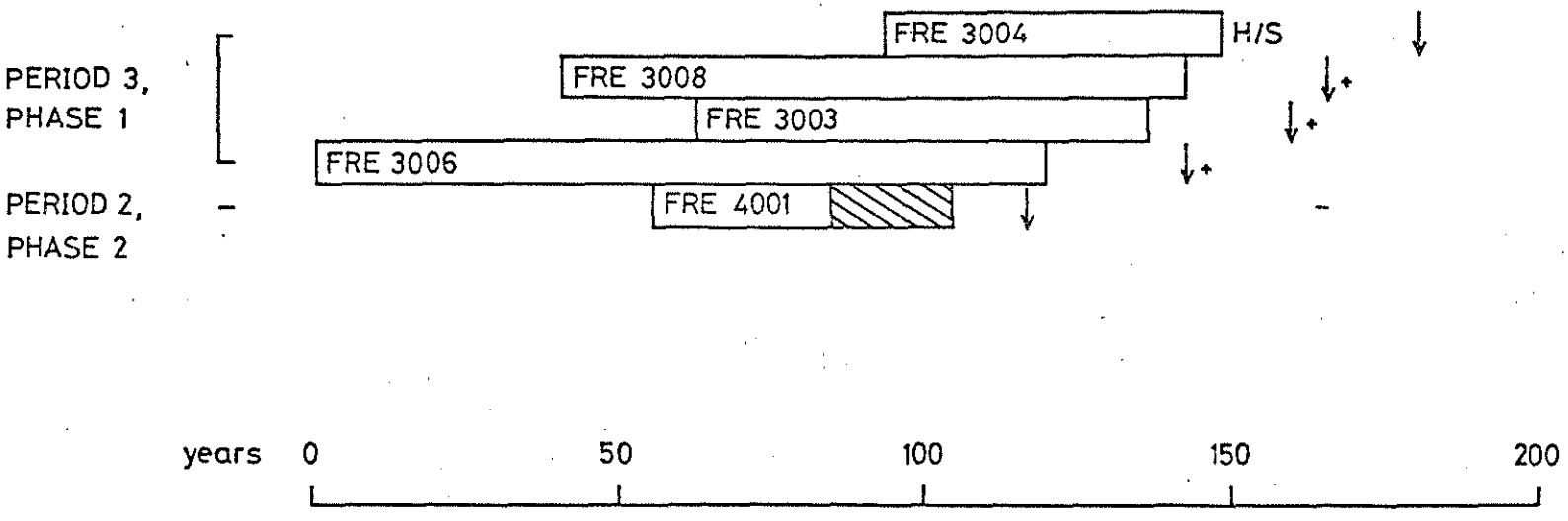

PERIOD 3,
PHASE 1
PERIOD 2,
PHASE 2
FRE 3004
H/S
FRE 3008
FRE 3003
FRE 3006
FRE 4001
years
0
50
100
150
200

Fig.7

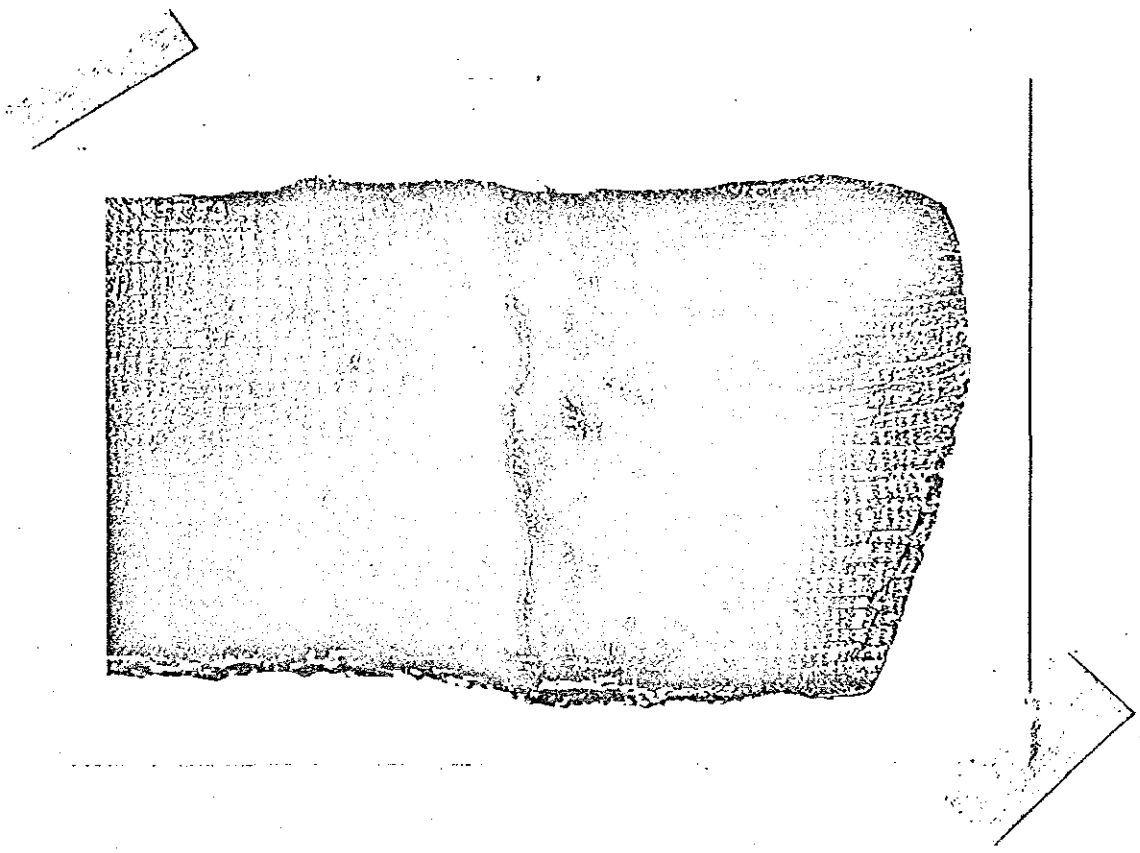
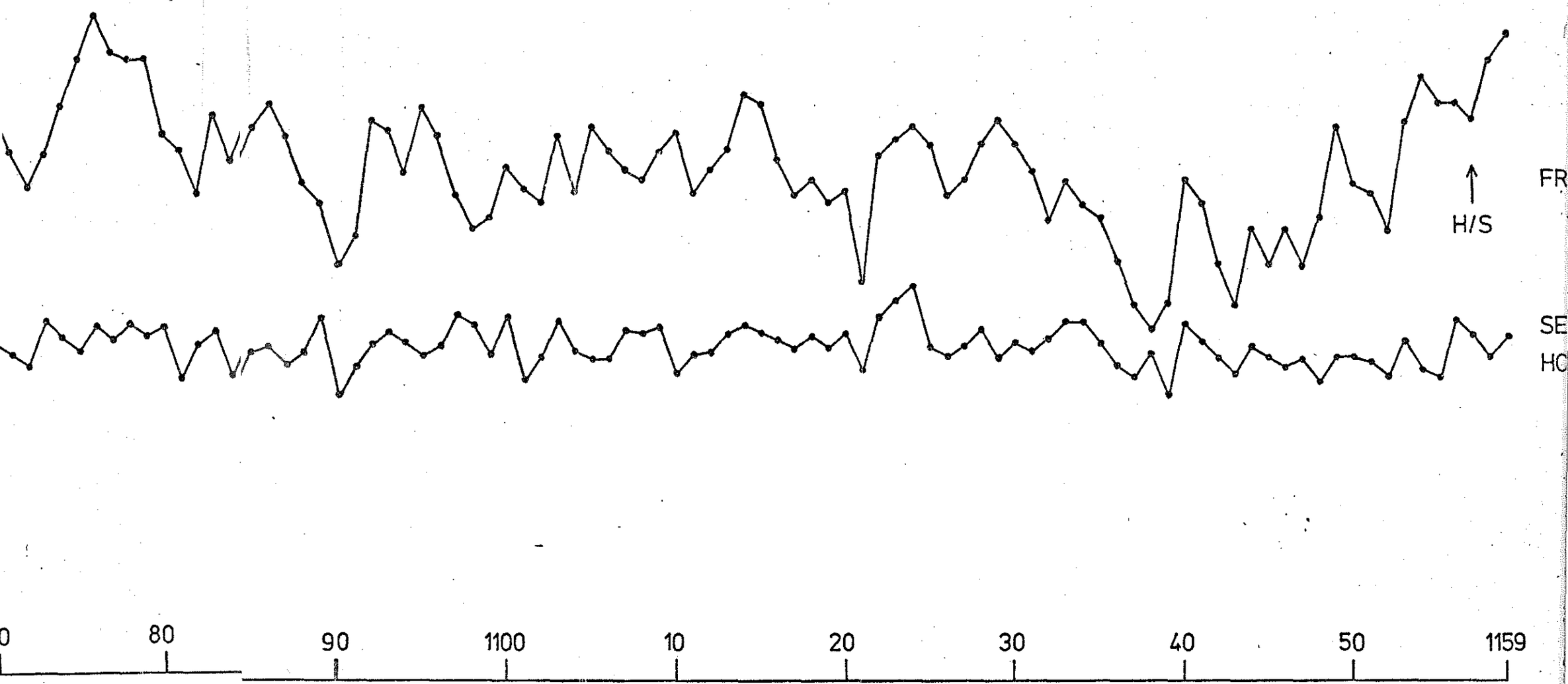


Plate 1. The outer edge of a section removed from sill-beam 378 showing the wide sapwood zone which must reach very close to the bark edge (38 rings). The wide ring on the right lies in arbitrary year 249.


H/S
FR
SE
HC
0
80
90
1100
10
20
30
40
50
1159

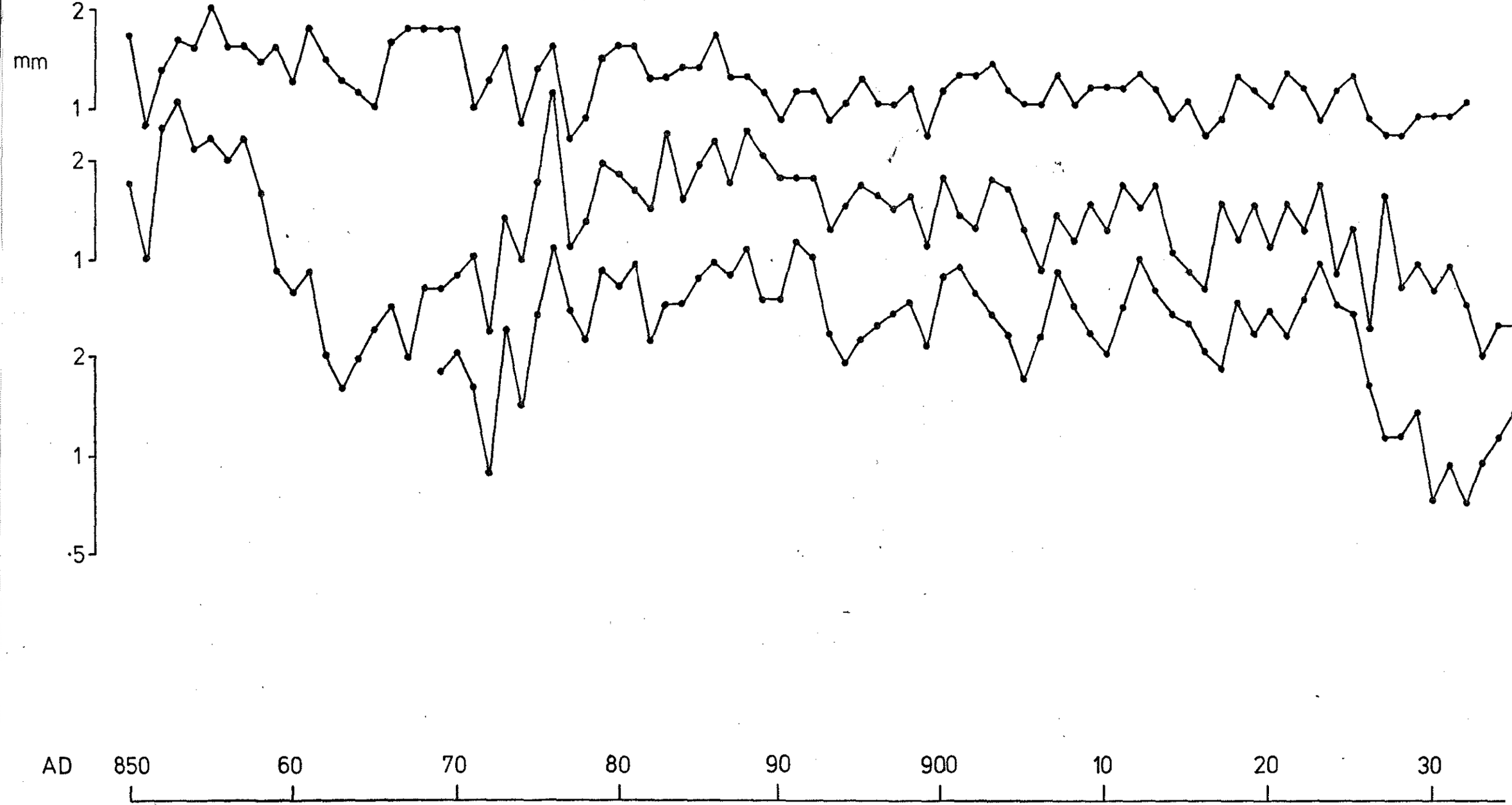


FIG 9

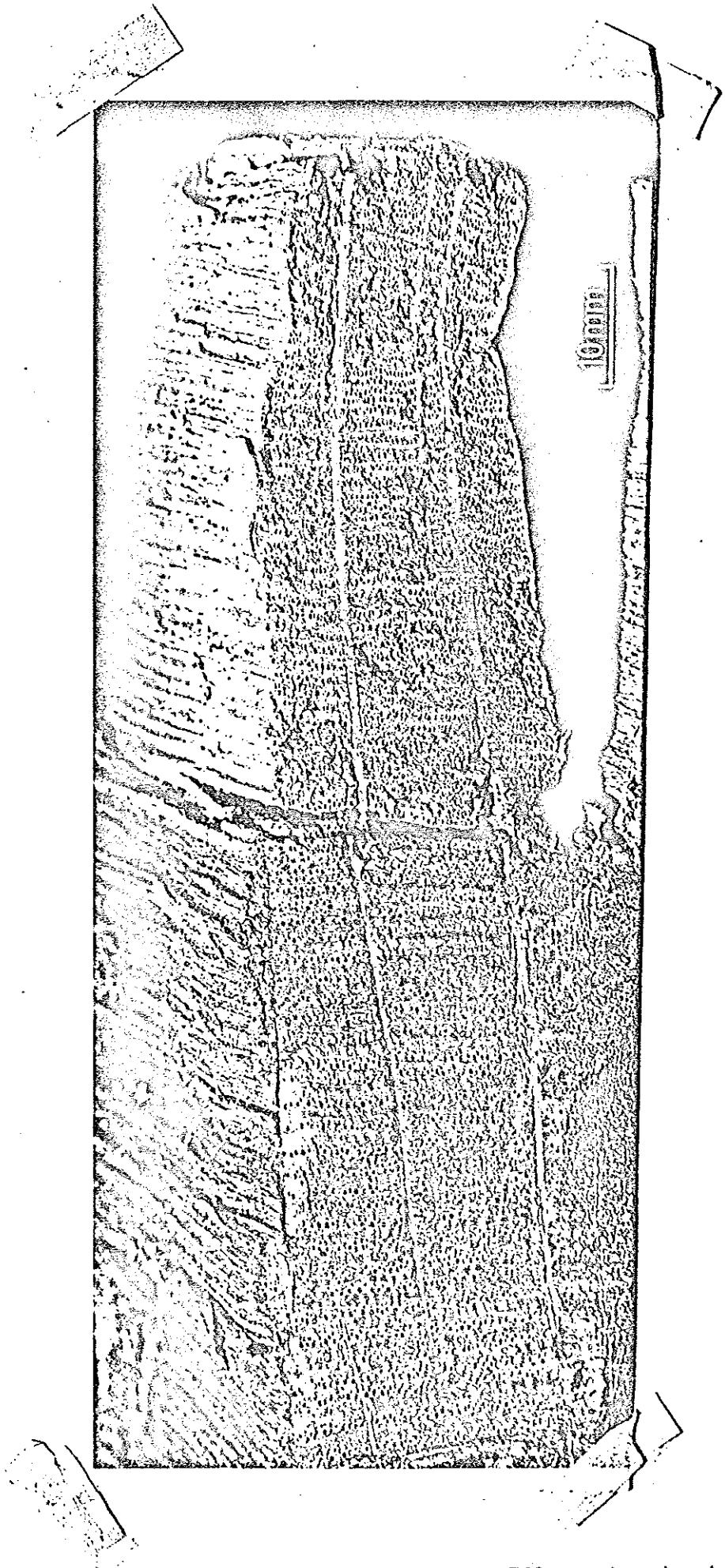


Plate 2. The rings of cradling timber 321 again showing sapwood on the right (the wood is rather dry and cracked, hence the poor surface on the sapwood).

APPENDIX

PERIOD 1 (ROMAN)

PHASE 3

FRE 369

68

39 26 18 44 33 24 33 16 22 45 22 37 52 32 29 29 41 31 30 36 26 21 32 19 22
18 22 23 23 20 14 18 26 22 16 23 21 13 15 10 13 6 7 5 4 5 5 5 5 3
3 4 4 4 5 3 3 3 5 6 4 6 5 4 4 3 4 7

FRE 677

217

48 42 35 29 28 23 33 38 50 34 36 41 34 43 39 47 41 32 17 26 30 25 25 21 15
6 8 9 15 12 10 14 15 14 13 11 20 16 14 11 19 17 20 13 12 8 13 11 10 10
10 12 9 7 11 7 11 8 5 8 10 7 12 9 11 14 12 8 8 18 14 19 16 14 21
12 14 13 17 12 17 14 16 23 12 10 10 8 17 20 22 18 16 17 21 14 17 19 17 17
20 27 23 23 20 17 21 17 19 19 23 18 24 26 27 22 20 16 11 24 20 18 16 21 22
21 15 16 12 15 9 19 23 19 15 18 18 16 15 13 19 17 13 10 11 15 16 13 12 17
14 12 12 15 12 16 17 15 11 10 8 16 21 17 12 19 13 13 11 14 11 15 16 17 11
11 12 15 11 14 9 12 10 8 8 10 12 13 11 10 10 8 10 7 12 16 13 11 10 8
11 12 11 10 9 9 9 7 9 7 9 7 7 10 9 7 10

FRE 680

79

22 24 26 19 30 27 19 18 17 17 13 18 19 21 15 20 14 17 19 27 25 24 17 12 11
15 18 13 13 11 18 10 12 8 14 16 12 18 23 19 16 18 18 23 20 26 20 22 23 11
19 14 23 26 24 15 12 17 28 22 31 27 13 17 15 23 15 27 18 16 20 26 23 15 17
8 15 11 21

FRE 681

57

36 27 29 31 48 52 49 52 54 51 36 32 29 22 26 22 18 20 13 22 18 21 17 24 15
27 25 17 16 13 11 10 14 21 10 9 18 16 12 17 22 13 20 10 15 19 19 16 10 17
14 13 11 7 13 11 13

PHASE 4

SM 190

51

10 15 19 19 32 53 43 44 33 28 50 42 33 34 27 38 33 45 50 50 54 45 55 39 40
27 30 43 30 14 15 29 35 38 40 42 37 50 58 42 57 58 55 68 70 85 52 55 64 80
65

SM 205

134

32 35 40 51 40 65 42 39 33 36 27 38 32 31 45 32 32 32 22 31 37 41 40 42 39
42 35 36 47 43 45 38 32 38 41 34 40 47 38 47 50 38 35 44 37 42 30 33 24 16
27 26 33 24 26 32 23 35 26 22 23 23 25 29 31 26 31 38 22 29 19 31 27 28 22
22 27 28 24 18 21 24 19 20 22 22 22 22 23 21 16 14 19 17 19 21 25 19 20 18
19 18 22 23 22 16 15 18 23 17 26 23 25 20 19 21 20 22 22 23 24 21 17 26 19
19 25 24 18 16 12 14 13 11

SM 212

62

50 40 40 39 59 38 47 53 55 54 45 51 38 25 23 28 25 31 48 31 31 28 23 45 37
33 25 25 20 39 47 24 22 17 17 19 25 20 18 30 31 26 28 32 28 31 23 27 42 27
28 40 56 43 30 31 16 21 17 19 33 20

SM 213

70

25 40 32 23 25 20 22 23 25 28 35 23 39 37 38 27 21 22 20 21 36 24 22 21 25
28 24 20 17 20 24 27 24 21 14 14 20 29 28 35 35 36 33 36 29 33 36 52 42 30
28 7 18 26 28 40 30 26 20 32 34 32 33 29 24 28 30 20 32 23

SM 236

197

55 46 40 34 16 14 16 23 24 22 23 31 25 27 30 34 37 29 34 35 26 22 24 20 13
19 22 22 19 14 20 21 19 29 24 20 13 17 19 25 30 31 27 32 27 12 11 8 16 16
25 25 24 31 14 17 15 13 14 12 14 17 20 15 13 17 19 16 17 18 14 15 19 18 10
12 21 12 14 13 14 15 12 14 12 12 13 15 14 13 17 17 17 20 15 14 10 9 11 12
12 13 18 13 8 8 8 8 6 6 9 12 12 12 14 13 17 12 9 18 15 19 8 9 9
12 11 11 11 11 12 13 15 16 17 19 19 15 13 7 11 16 12 13 15 11 12 11 10 9
11 15 13 13 14 17 20 17 17 17 19 16 12 12 12 12 15 17 14 12 10 15 14 12 14
15 12 10 9 9 12 12 10 11 10 12 11 12 12 12 12 15 14 12 11 12 13

SM 243

80

9 12 19 17 12 9 4 3 12 13 12 19 24 22 27 22 33 33 38 31 19 33 60 45 37
35 23 29 37 33 50 45 45 36 40 34 46 42 39 40 36 42 39 56 47 42 36 45 39 43
43 27 23 30 41 43 31 22 22 28 22 17 17 16 14 16 17 26 15 30 35 31 23 20 16
19 20 18 24 15

SM 279

92

37 20 44 65 22 48 25 40 32 52 38 45 44 35 32 34 37 37 32 44 34 31 42 37 37
37 25 36 30 15 23 26 18 32 29 27 21 15 28 12 17 16 17 17 22 17 21 24 22 22
24 18 19 24 22 24 13 20 22 25 17 23 17 23 13 19 24 18 19 15 18 20 12 22 15
11 14 15 16 14 19 19 11 12 16 16 17 9 12 13 12 8

SM 311

218

13 18 18 24 28 32 19 21 24 24 23 25 23 23 25 19 19 27 23 24 22 24 24 24 26
23 33 33 30 25 27 26 16 14 20 26 28 28 31 38 33 32 30 32 40 31 30 30 34 34

SM 311
218
13 18 18 24 28 32 19 21 24 24 23 25 23 23 25 19 19 27 23 24 22 24 24 24 26
23 33 33 30 25 27 26 16 14 20 28 28 28 31 38 33 32 30 32 40 31 30 30 34 34
24 24 21 36 38 33 31 29 27 25 24 30 26 17 16 19 20 24 26 21 24 18 17 11 11
10 17 16 17 19 17 17 11 15 12 13 11 10 12 12 21 14 13 18 14 15 22 17 13 12
15 18 15 15 21 22 35 37 26 25 22 19 21 31 25 23 23 17 24 23 22 24 20 18 15
11 17 17 18 13 15 16 17 18 15 14 14 17 18 18 20 17 19 18 18 14 16 16 15 17
11 12 18 23 15 12 12 12 9 16 18 13 15 18 13 12 10 7 10 14 11 10 12 10 11
10 15 11 15 16 16 15 16 14 15 11 11 12 14 14 9 14 12 12 15 12 13 10 11 13
12 8 17 15 16 15 12 16 14 16 11 15 12 12 11 11 8 11
SM 321
138
first two values not included in mean curve, figures or tables
(24 22) 18 13 18 15 24 21 19 22 15 12 10 11 16 26 23 19 19 15 11 11 12 17 20
24 12 17 16 15 11 9 9 13 14 16 16 18 19 22 24 14 12 12 16 19 16 19 18 15
13 13 12 12 14 14 17 19 21 11 14 15 17 14 15 17 16 14 11 13 15 20 17 17 10
19 16 14 15 15 15 13 9 15 7 7 8 9 10 9 15 11 12 8 7 11 12 11 9 10
12 12 13 8 15 11 12 10 10 8 6 7 9 10 10 10 12 11 11 9 6 8 8 12 16
17 13 13 12 12 13 12 9 8 12 19 14 13
SM 322
111
28 33 32 27 34 35 27 30 36 24 22 28 35 21 22 30 27 20 20 14 15 15 14 14 14
13 14 13 12 14 14 16 17 15 19 15 13 16 13 15 12 15 13 15 14 14 8 13 15 18
23 19 22 22 22 13 14 9 19 18 20 19 15 16 19 20 14 15 19 19 17 22 26 20 18
19 12 13 10 12 16 19 18 28 13 17 15 16 12 15 17 35 15 18 22 17 24 17 33 21
14 16 18 11 10 16 15 15 12 10 10
SM 326
49
45 40 39 40 50 55 56 43 34 49 43 56 57 43 49 53 22 32 34 33 44 38 35 34 22
41 30 21 29 27 34 39 37 28 32 18 29 32 27 31 31 34 27 15 20 19 29 18 22
SM 378
212
29 47 28 22 17 28 36 29 30 35 46 36 34 36 30 19 18 18 19 20 20 23 27 27 27
18 16 14 17 18 22 20 21 22 17 17 15 19 22 24 22 22 24 18 20 21 19 13 19 15
17 16 16 17 17 17 20 18 20 18 15 12 11 15 14 18 15 16 18 16 19 22 19 19 18
16 12 10 15 15 14 15 15 15 12 13 11 10 8 10 11 14 15 13 15 17 15 11 11 16
16 18 12 14 17 18 15 11 11 11 9 10 13 13 12 13 18 15 14 8 12 14 14 14 16
12 16 14 17 16 19 17 19 16 17 17 19 17 20 19 23 18 14 18 18 20 17 18 16 12
12 15 17 14 22 25 23 22 15 22 19 20 22 19 19 21 18 19 15 19 14 18 21 22 15
14 15 17 22 17 19 19 16 14 19 17 22 22 19 16 14 14 17 15 15 14 12 14 16 12
18 14 13 11 11 13 12 10 9 11 16 18
SM 386
61
8 12 13 18 19 18 10 18 23 17 23 21 25 25 19 24 35 22 20 23 16 19 11 30 36
22 25 14 23 35 41 37 40 23 26 29 19 26 19 17 16 16 26 29 26 14 22 24 14 15
15 15 20 28 25 24 24 23 19 9 13
FRE 5002
115
55 50 68 67 63 72 76 56 47 57 68 50 33 26 49 63 58 45 28 35 24 26 51 63 45
39 44 42 33 11 25 23 27 38 41 54 31 27 19 77 17 24 44 32 32 27 26 21 18 32
38 37 20 24 36 33 30 22 13 18 20 27 23 27 21 28 29 12 13 18 14 25 16 18 16
12 19 23 17 21 21 30 24 18 12 11 16 29 28 23 20 16 14 10 5 7 10 15 17 10
8 12 13 13 22 20 16 19 11 17 6 5 10 12 10
FRE 5003
152
38 30 49 57 56 52 28 20 38 26 41 32 53 30 41 38 27 22 16 33 17 16 22 24 18
16 12 12 10 11 12 16 12 18 14 14 14 20 17 13 18 16 11 23 19 17 14 13 19 13
11 8 16 17 20 16 8 10 6 7 7 6 5 8 6 5 9 7 7 11 5 8 10 8 12
8 13 17 9 12 16 12 26 16 20 8 13 8 10 15 11 15 14 13 13 22 35 49 34 32
23 16 41 25 27 20 19 26 19 19 19 18 17 16 25 34 25 20 14 12 12 13 8 18 12
14 8 12 7 16 31 27 21 24 26 24 19 28 35 25 36 47 34 30 17 33 62 59 32 63
29 46
FRE 5013
125
43 44 31 44 53 41 27 26 34 40 25 27 45 52 36 45 48 44 33 29 48 37 32 33 38
31 26 13 18 19 28 21 21 37 25 23 17 7 17 16 28 19 22 27 24 15 17 26 26 20
14 21 19 23 22 16 11 17 14 25 26 24 21 20 26 9 15 12 18 16 15 13 12 14 15
17 14 13 16 20 19 18 9 11 14 13 14 13 12 11 13 8 6 6 12 14 13 10 11 12
14 12 16 12 9 14 10 15 8 6 12 9 9 14 18 11 15 12 8 13 12 11 7 9 7
FRE 5014
202
26 12 19 29 45 39 36 34 64 26 21 20 30 25 19 25 30 23 50 36 30 32 23 18 17
28 16 10 19 12 13 13 9 9 8 9 13 15 13 16 18 16 15 18 13 11 17 14 13 17
22 22 16 12 15 14 9 9 18 15 14 17 14 12 7 11 8 7 9 15 9 16 33 24 29
34 19 17 31 11 7 9 14 19 15 22 17 37 29 18 28 10 20 15 25 21 16 18 18 15
28 18 18 20 32 36 20 18 39 25 19 12 16 15 16 22 21 13 17 11 21 31 20 19 23
18 17 11 9 17 12 14 8 15 19 23 15 10 12 17 15 11 20 13 18 16 23 19 10 10
18 25 27 14 16 11 16 14 40 12 18 28 15 12 9 14 22 16 16 8 11 11 6 9 10
14 17 10 14 12 9 14 11 13 16 22 19 19 9 16 18 15 13 15 12 16 14 7 7 10
6 10
PHASE 8

PHASE 8
FRE 374
41
40 25 33 25 22 34 30 28 15 28 27 26 34 30 33 24 24 30 27 34 26 22 31 35 29
24 32 34 31 29 26 31 17 29 35 33 33 22 27 19 23
FRE 375
64
16 9 14 9 5 10 15 12 18 8 18 19 20 11 13 20 12 20 14 18 17 19 15 17 25
18 12 23 20 29 15 14 22 24 20 30 26 25 20 20 24 30 17 27 45 26 20 26 17 22
26 31 26 20 17 16 20 18 25 31 35 21 19 31
FRE 376
58
37 22 28 15 8 13 20 9 13 11 17 16 23 26 29 16 14 20 12 18 11 18 12 20 11
21 18 12 18 20 20 23 19 12 20 24 22 24 23 20 23 19 22 27 16 21 20 25 17 25
16 23 22 12 24 20 18 17
FRE 377
62
28 16 5 7 21 16 13 20 9 12 11 15 15 13 16 12 9 16 24 26 29 15 21 28 18
28 13 29 21 31 27 27 32 26 34 31 24 28 27 22 18 20 19 13 12 20 16 14 13 10
8 10 13 17 15 13 15 16 13 10 18 15
FRE 378
48
21 26 37 30 25 24 36 32 18 25 21 13 18 22 27 24 16 16 30 19 27 21 26 14 17
21 17 19 8 9 12 20 16 18 20 17 16 14 17 20 19 18 20 24 20 14 16 19
FRE 379
47
28 15 26 32 19 24 36 28 33 16 28 25 29 40 35 33 26 29 26 28 30 25 15 20 26
20 17 24 21 19 15 12 14 7 13 21 18 18 11 11 12 10 7 12 16 12 21
PERIOD 2 (SAXON)
PHASE 2
FRE 4001A
55
22 22 30 33 29 31 19 23 25 25 30 28 26 17 27 21 12 14 14 13 10 10 5 6 7
8 4 5 4 6 7 9 6 7 5 3 4 3 3 4 5 6 6 7 8 6 9 6 4 6
7 10 14 9 8
PERIOD 3 (LATE SAXON=EARLY MEDIEVAL)
PHASE 1
SM 7
73
13 14 14 12 11 14 12 18 12 15 17 19 23 28 17 17 19 15 14 16 15 27 35 21 12
8 5 7 20 16 10 7 21 31 29 22 19 18 14 21 23 23 21 31 20 20 16 8 9 8
9 10 11 17 10 13 15 16 19 25 21 13 12 8 8 7 14 13 22 20 32 19 14
SM 130
62
55 48 52 40 47 52 50 42 28 40 33 49 34 47 43 30 45 37 37 28 28 35 34 34 19
25 33 34 22 24 32 25 27 25 29 21 34 42 32 21 36 37 34 36 32 43 32 40 29 37
42 30 27 29 27 19 31 27 27 28 27 20
SM 183
166
35 38 21 27 37 28 28 37 38 34 44 42 42 32 43 44 35 42 38 30 34 27 36 10 7
4 4 4 6 8 7 6 8 9 11 7 8 8 7 8 8 9 12 10 13 10 18 17 12 17
15 22 17 13 14 15 12 13 10 19 12 20 15 17 15 12 15 16 14 15 20 11 9 12 18
21 17 19 18 14 14 12 14 17 9 13 16 15 20 15 15 14 15 12 17 14 12 11 10 16
17 17 17 17 10 12 15 9 13 15 8 9 14 15 15 12 12 13 13 16 12 12 11 9 11
11 9 10 12 10 10 11 8 11 12 12 13 11 10 10 12 10 11 11 11 12 11 9 10 8
9 12 11 10 12 11 9 11 12 9 8 8 9 9 9 10
SM 273
75
27 15 17 18 17 19 26 36 32 34 24 24 29 29 21 27 19 29 34 34 30 30 24 22 23
55 30 22 29 30 42 42 42 39 35 35 45 46 50 50 40 40 39 38 40 38 43 42 54 30
37 48 48 42 30 35 25 18 22 33 48 46 29 19 29 26 25 36 27 19 23 35 23 26 21
FRE 575A
58
23 32 24 27 47 37 22 25 26 22 42 36 33 36 40 21 28 34 26 15 32 39 20 43 14
42 29 52 42 33 20 28 52 32 32 25 19 18 21 24 13 8 11 22 15 27 29 14 21 15
24 9 16 7 15 13 15 11
FRE 575B
79
45 39 30 18 24 16 19 21 17 19 23 20 26 23 20 19 9 12 16 19 17 14 13 10 12
19 14 8 10 6 6 5 11 6 17 17 12 16 8 6 5 4 5 6 6 12 16 28 20 10
8 16 23 18 23 19 15 17 15 21 14 12 15 13 23 17 22 19 30 24 22 20 8 15 22
19 14 14 16
FRE 3003
76
12 15 30 18 23 16 21 18 21 15 17 24 21 19 15 13 22 16 22 28 11 15 13 27 25
24 24 28 23 12 16 15 13 22 24 26 23 23 15 11 18 20 12 9 11 17 22 25 16 22
20 23 20 21 24 28 24 22 16 22 18 16 20 22 20 15 18 21 17 16 20 14 20 16 19
22
FRE 3004A
56
11 10 9 15 11 26 18 7 11 11 11 12 14 17 13 14 19 16 24 17 25 26 23 20 25
16 16 13 21 24 21 23 23 24 29 21 20 14 12 12 9 14 15 18 17 17 13 16 15 17
21 19 26 13 17 12

```
 56
 11 10  9 15 11 26 18  7 11 11 11 12 14 17 13 14 19 16 24 17 25 26 23 20 25
 16 16 13 21 24 21 23 23 24 29 21 20 14 12 12  9 14 15 18 17 17 13 16 15 17
 21 19 26 13 17 12
FRE 3005B
100
 18 20 16  9 24 14 27 42 28 23 36 33 38 22 28 28 34 37 35 41 29 29 43 39 23
 19 22 24 26 28 21 34 36 30 26 23 17 23 35 28 23 20 28 39 31 26 25 20 18 28
 23 26 23 29 37 28 27 16 11 11 13  7  9  7  9 11 13 14 16 12 11  7  9  4  5
  6 10 14 24 19 12 24 16 13 10  6  8  9 15 13 12 14 16 12 22 20 12 19 14 30
FRE 3006A
 21 13 21 20 10 17 14 13 11 13 12 16 11 20 16 30 25 24 26 20 13 24 10  9  7
  9  7 12 19 24 22 16 35 27 22 33 28 26 25 14 11 12 16 11 18 15  8 11  8 14
 10  9  8 11 11 15 13 30 23 45 33 21 18 26 21 16 19 13 17 21 36 30 35 48 47
 31 40 42 30 24 24 36 24 19 24 18 24 21 25 21 27 22 36 38 22
FRE 3008A
103
 10  6  6 10  8 11 14 11 12 16 24 18 15 17 15  9  7 18 11 14 21 18 13 15 14
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 21 16 23
PHASE 2
FRE 597
 76
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 27
FRE 3001
 89
 23 24 22 34 12 14 17 14 10  8 14 13 11 24 19  9 10 14 24 29 26 21 15 11 16
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PHASE 4
FRE 576
 71
 34 15 29 31 32 30 24 30 39 39 53 31 30 32 34 16 14 21 23 27 26 20 20 17 21
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FRE 592
127
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 14 16
FRE 8004
115
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  8 10  8 11 20 14 13 10 21 28 24 24 22 32 38
PHASE 5
FRE 543
 70
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FRE 10001
102
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