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TREE-RING ANALYSIS OF TIMBERS FROM PETERBOROUGH CATHEDRAL, PETERBOROUGH, CAMBRIDGESHIRE: BOARDS FROM THE PAINTED NAVE CEILING - PHASE 2

C Groves

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Author's address :-

C Groves
SHEFFIELD DENDROCHRONOLOGY LABORATORY
Archaeology Research School
University of Sheffield West Ct 2 Mappin St
Sheffield
S1 4DT

Tree-ring Analysis of Timbers from Peterborough Cathedral, Peterborough, Cambridgeshire:

Boards from the Painted Nave Ceiling - *Phase 2*

Cathy Groves
May 2000

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Author's address:
Sheffield Dendrochronology Laboratory
Research School of Archaeology & Archaeological Science
Department of Archaeology & Prehistory
University of Sheffield
West Court
2 Mappin Street
Sheffield S1 4DT

Tel/fax: 0114 276 3146
Email: c.m.groves@sheffield.ac.uk

TREE-RING ANALYSIS OF TIMBERS FROM PETERBOROUGH CATHEDRAL, PETERBOROUGH, CAMBRIDGESHIRE: BOARDS FROM THE PAINTED NAVE CEILING - *PHASE 2*

Introduction

This document is a technical archive report on the dendrochronological analysis of boards from bays 2 and 3, towards the eastern end of the painted nave ceiling, Peterborough Cathedral, Peterborough (TL194987). It is the second of a series of interim reports that summarise the dendrochronological results from each separate phase of the analysis as the restoration project proceeds along the nave. The final publication will draw together the information from the interim reports into a more comprehensive dendrochronological record presenting the overall conclusions. It is beyond the dendrochronological brief to describe the ceiling in detail or to undertake the production of detailed drawings. As part of a multidisciplinary study of the ceiling, elements of this report may be combined with detailed descriptions, drawings, and other technical reports to form a comprehensive publication on the ceiling. The conclusions presented here may therefore have to be modified in the light of subsequent work.

Peterborough Cathedral lies in the centre of Peterborough, and is now in the unitary authority of the City of Peterborough, though traditionally in the Soke of Peterborough, part of Northamptonshire (Fig 1). A Benedictine Abbey was established on the site *c* AD 960. The present cathedral, built between *c* AD 1118 and *c* AD 1238 (Higham 1990), is one of the finest surviving and most complete twelfth- and thirteenth-century structures in England. One of its most notable features is the nave ceiling (Fig 2) which consists of a unique series of painted panels. The pattern of boards allows the ceiling to be divided into ten bays, with ten large diamonds, one per bay, encompassing four smaller ones (Fig 3). This painted wooden ceiling is the largest surviving medieval example of its type in Europe. Its presence however is fortuitous as it reflects the failure in the late-twelfth or early-thirteenth centuries to provide the church with rib vaulting in the nave when it became clear that the structure would be unable to bear the weight of stone vaulting throughout. The date proposed for the painting of the ceiling is thirteenth century and probably during the period *c* AD 1220-40 (Binski pers comm; Mackreth pers comm).

The nave ceiling painted panels are the subject of a 3-4 year conservation programme partially funded by English Heritage. As part of this two separate, though clearly linked, dendrochronology projects have been commissioned at the request of David Heath, English Heritage Cathedral Architect. The first project, now completed, was the analysis of the relic nave roof above the ceiling boards, including the joists to which the boards are attached, and the related roof of the north-west portico. The results of this confirm the interpretation, based on documentary and structural evidence, of the construction sequence of the nave and north-west portico (Tyers 1999a). The second of these projects, and the subject of this report, is the analysis of the painted boards. This is, by necessity, being undertaken in a series of phases as the scaffolding and conservation programme progress westwards along the nave. Phase one of the dendrochronological analysis is now complete and the results presented in Groves (2000). The primary purpose of the dendrochronological analysis is to provide dating evidence for the insertion of the primary oak ceiling boards and, through a comprehensive sampling strategy, to detect any variation in date along the length of the nave. This should confirm or refute the previously accepted dating evidence from documentary sources and other specialist information. It was also hoped to provide further evidence concerning the geographical origin of the oak boards. A secondary aim of this second phase of the ceiling analysis was to provide information concerning the type of wood used for the softwood replacement boards in order to identify any difference in types used in the two major refurbishment phases in the AD 1740s and AD 1830s, and also to determine the viability of dendrochronological analysis of these boards.

Methodology

Professional practice at the Sheffield Dendrochronology Laboratory follows that described in English Heritage (1998). The following summarises relevant methodological details used for the dendrochronological analysis of the nave ceiling boards.

Prior to the sampling for phase one an assessment survey was undertaken to determine whether the original oak boards were suitable for analysis, how this could be undertaken *in situ*, and to allow a suitable sampling strategy to be formulated. Oak (*Quercus* spp.) is currently the only species used for routine dating purposes in the British Isles, although research on other species is being undertaken (eg Tyers 1997a; Groves 1997). Timbers with less than 50 annual growth rings are generally considered unsuitable for analysis as their ring patterns may not be unique (Hillam *et al* 1987). Thus oak timbers are generally sought which have at least 50 rings and if possible either bark/bark edge or some sapwood surviving (see below).

In standing buildings samples are generally removed from selected timbers in the form of either cross-sectional slices or cores. Alternatively if the removal of samples is inappropriate, *in situ* measurement, high resolution photography, or taking an imprint of the wood structure can, in instances where the end-grain is visible, accessible and cleaned sufficiently to reveal the ring sequence clearly, replace the need for the physical removal of a sample. The usual procedure with boards or panel paintings, where sampling is unacceptable, is for the analysis to be undertaken in the laboratory by carefully cleaning up the cross-sectional surface and mounting the intact board in a protective cradle attached to the travelling stage. However the boards in the nave ceiling were to remain *in situ*. The cross-sectional surface of some of the boards seen during the phase one assessment were certainly accessible, and it was assumed that this would be the case during the subsequent phases as the scaffolding was moved to allow access to the remaining bays. The sampling technique selected for phase one, which had to take into account the requirement for minimal intervention, had proved successful and the decision was taken to apply this to the subsequent phases of work. The cross-sectional surface of each selected board was prepared by a combination of sanding, use of a surgical blade, compressed air, and soft brushes. The ring sequence was obtained by taking a series of overlapping imprints of the wood structure using 'FIMO' (Leuschner and Leuschner 1996).

The 'FIMO' imprints were heat-hardened to ensure permanence. Any imprints which failed to contain the minimum number of rings or had unclear ring sequences were rejected. The sequence of growth rings in the samples selected for dating purposes were measured to an accuracy of 0.01mm using a purpose built travelling stage attached to a PC Windows-based measuring system (Tyers 1997b). The ring sequences were plotted onto semi-logarithmic graph paper to enable visual comparisons to be made between them. In addition cross-correlation algorithms (Baillie and Pilcher 1973; Munro 1984) were employed to search for positions where the ring sequences were highly correlated. The Student's *t* test is then used as a significance test on the correlation coefficient. Those quoted below are derived from the original CROS algorithm (Baillie and Pilcher 1973). A *t* value of 3.5 or over is usually indicative of a good match (Baillie 1982, 82-5), provided that high *t* values are obtained at the same relative or absolute position with a range of independent sequences and that the visual match is satisfactory.

The ring sequences from each series of imprints from a single board were compared to ensure that they crossmatched and then were combined to form the individual board sequences. Dating is usually achieved by cross-correlating, or crossmatching, ring sequences within a phase or structure and combining the matching patterns to form a phase or site master curve. This master curve and any remaining unmatched ring sequences are then tested against a range of reference chronologies, using the same matching criteria as above. The position at which all the criteria are met provides the calendar dates for the ring sequences. A master curve is used for absolute dating purposes whenever possible as it enhances the common climatic signal and reduces the background 'noise' resulting from the local growth conditions of individual trees.

During the crossmatching stage an additional important element of tree-ring analysis is the identification of 'same-tree' timber groups. The identification of 'same-tree' groups is based on very high levels of similarity in year to year variation, longer term growth trends, and anatomical anomalies. Such information should ideally be used to support possible 'same-tree' groups identified from similarities in the patterns of knots/branches during detailed recording of timbers for technological and woodland characterisation studies. Timbers originally derived from the same parent log generally have t values of greater than 10.0, though lower t values do not necessarily exclude the possibility. It is a balance of the range of information available that provides the 'same-tree' link.

The crossdating process provides precise calendar dates only for the rings present in the timber. The nature of the final ring in the sequence determines whether the date of this ring also represents the year the timber was felled. Oak consists of inner inert heartwood and an outer band of active sapwood. If the sample ends in the heartwood of the original tree, a *terminus post quem* for the felling of the tree is indicated by the date of the last ring plus the addition of the minimum expected number of sapwood rings which may be missing. This is the date after which the timber was felled but the actual felling date may be many decades later depending on the number of outer rings removed during timber conversion. Where some of the outer sapwood or the heartwood/sapwood boundary survives on the sample, a felling date range can be calculated using the maximum and minimum number of sapwood rings likely to have been present. Alternatively, if bark-edge survives, then a felling date can be directly obtained from the date of the last surviving ring. In some instances it may be possible to determine the season of felling according to whether the ring immediately below the bark is complete or incomplete. However the onset of growth can vary within and between trees and this, combined with the natural variation in actual ring width, means that the determination of felling season must be treated cautiously. The sapwood estimate applied must be appropriate to the source of the timber as there is a geographical variation in the number of sapwood rings present which increases from east to west across north-west Europe (Baillie *et al* 1985; Hillam *et al* 1987; Wazny and Eckstein 1991).

The dates obtained by the technique do not by themselves necessarily indicate the date of the structure from which they are derived. Evidence indicates that seasoning of timber for structural purposes was a fairly rare occurrence until relatively recent times and medieval timber was generally felled as required and used whilst green (eg Rackham 1990; Charles and Charles 1995). Physical evidence for the rapid use of trees is widespread in buildings as many show clear evidence of warping or splitting after having undergone conversion. However it is necessary to incorporate other specialist evidence concerning the reuse of timbers and the repairs or modifications of structures, as well as factors such as stockpiling, seasoning, and transport, before the dendrochronological dates given here can be reliably interpreted as reflecting the construction date of phases within the structure.

Assessment for dendrochronological analysis of the softwood boards was generally undertaken by visual inspection of the underside of the boards but, following the lifting of some small sections of hessian, more detailed inspection was carried out on some boards from above. The criteria used during assessment to determine the suitability of softwoods for dendrochronological analysis are identical to those applicable to oak. In order to facilitate the identification of the type of softwood used for the later replacement boards it was necessary to remove small cubes of wood, ranging in size from 5mm to 10mm. The wood type of the selected boards was determined through reference material in the form of permanent slides, an identification key (Schweingruber 1990), and a computer database (GUESS - see Wheeler *et al* 1986).

Results

The nomenclature and numbering scheme of Donald Mackreth, Cathedral Archaeologist, and the Perry Lithgow Partnership are followed throughout this report. Figure 4 indicates the location of the panels (28/I to 35/IV) analysed in this phase. The term sampling is usually used to imply the physical removal of a section of wood, however in this study as far as the oak boards are concerned it refers to the taking of imprints.

Conifers

The need to remove small sections of wood limited the selection of timbers to those extending beyond the ashlar boards. Further limitations were imposed by patches from later repair work in AD 1926 preventing access to the overhanging ends of the AD 1740s and AD 1830s boards, as well as the positions of structural timbers preventing access to some boards. However in spite of these difficulties a series of 19 samples were taken, the locations of which are indicated in Figure 5 and Table 1. Microscopic identification of the timbers indicated the presence of two wood types. It has not been possible to determine the wood type down to species level for either of these types as various groups of species have very similar anatomical features. This is exacerbated by the problem of unknown geographical origin. The two types, both conifers in the Pinaceae family, are as follows:

Type A is either *Pinus sylvestris* L. (Scots pine), *P. mugo* Turra (Mountain pine), *P. nigra* Arnold (Black pine) or *P. resinosa* (Red pine). *P. sylvestris* occurs throughout Europe; *P. mugo* and *P. nigra* are native to central/southern Europe; and *P. resinosa* is a native of North America. *P. sylvestris* and *P. mugo* cannot be distinguished on the basis of their wood anatomy. *P. nigra* can sometimes be distinguished from *P. mugo* and *P. sylvestris* as the early/latewood transition may be more abrupt than in the other two species (Schweingruber 1990, 131). *P. resinosa* cannot normally be distinguished from these three European species on the basis of its wood anatomy. Fifteen of the boards proved to be wood type A (Table 1).

Type B is either *Picea* spp. (Spruce) or *Larix* spp. (Larch). The various species in the genus *Picea* cannot be distinguished from one another on the basis of their wood anatomy and, anatomically, a clear cut differentiation between the genus *Picea* and *Larix* is not possible (Schweingruber 1990, 115). However in *Larix* the transition between the earlywood and latewood generally tends to be quite abrupt where as it is more gradual in *Picea*, and the heartwood of *Larix* is generally reddish whilst that of *Picea* tends to be indistinct. Based on these tendencies it is thought that the boards are more likely to be *Picea*. Various species of the genus *Larix* and *Picea* occur in both Europe and North America. Only four boards proved to be of this wood type (Table 1).

The growth rate of each sample was estimated as being less 2 mm/year, 2-4 mm/year, or greater than 4mm/year (Table 1), though clearly this is only on the evidence of a small number of rings. The age trends in growth (eg Schweingruber 1988, 121) will result in samples from the innermost section of the board generally having wider rings than the outermost section. It is possible that the type B samples tend to be faster grown than the type A but sample numbers are too small to be certain of this observation.

The assessment of dendrochronological potential indicated that there was a significant proportion of conifers with sufficient rings for analysis. However the analysis of conifers in this country is in its infancy and is currently the subject of a research project funded by English Heritage (see below).

<u>Oaks</u>

A detailed assessment of the oak boards in bays 2 and 3 was carried out immediately before sampling in July AD 1999. As in phase one the majority of oak boards contained sufficient rings for analysis but the major determining factor in board selection was simply whether the cross-sectional surface at the end of the board was accessible. Cross-sections which were accessible but badly eroded were rejected as these would not provide a suitable surface for the 'FIMO' imprints without the removal of significant quantities of wood. Sapwood was once again noticeable by its absence and none of the primary oak boards, sampled or not, showed any evidence for the presence of sapwood. The absence of sapwood on the boards is typical of panelling and panel paintings because its more friable nature makes it inappropriate for such purposes. It would cause severe problems where panels were jointed together and severe damage to a painting where the sapwood rotted and was lost.

Details of the 13 boards selected for sampling are presented in Table 2 and Figure 6. A series of overlapping imprints were taken from each board. A total of 51 imprints were taken from the 13 boards. The number of imprints taken from each board was variable according to board-specific problems, such as particularly awkward access, surface degradation, and presence of bands of very narrow rings. Duplicate sets of imprints were taken from each board in order to minimise any difficulties during measurement but also as access would not be possible following the removal of the phase two scaffolding. Notes were made for each sampled board to indicate inaccessible sections, including length and rough ring counts, so that an allowance could be made for these unmeasured rings.

Only one imprint was totally rejected as the ring sequence was not sufficiently clear for reliable measurement. This rejection rate has decreased significantly compared to phase one when 18 of the 45 imprints were rejected. The remaining 50 imprints were measured and initially analysed in single board groups. Within each board group those ring sequences which crossmatched were combined to produce an individual board sequence (Fig 7a-r; Tables 3a-o), though five boards (**35-I-d, 33-I-c, 32-III-i, 32-IV-cc,** and **32-III-x**) are represented by an inner and an outer section which cannot be linked because of either a break in the board, a band of unmeasurable very narrow rings, or the overlap is insufficient for a match to be proven either statistically or visually. Imprints cannot provide the detailed anatomical features evident when examining the cleaned cross-sectional surface of the wood directly. This has an adverse affect on the ability to reliably measure bands of narrow rings and on the ability to resolve sections where the rings are staggered across rays. Thus the use of imprints requires increased reliance on visual comparison for problem solving in order to ensure that an accurate and reliable ring sequence is obtained. In some instances these problems, combined with the fact that the boards themselves cannot be re-sampled once the scaffolding is removed, can result in having to work with very short overlaps between imprint ring sequences. Short overlaps cannot be reliably tested using the standard statistical methods used. Hence visual comparison of the ring sequences, in conjunction with the known length of overlap in millimetres between two imprints recorded during sampling and also the visual characteristics present on duplicated sections of imprints (Fig 8), allows imprint ring sequences with only short overlaps to be reliably combined. If such board sequences are also dated a further check on the reliability of the short overlaps is carried out by testing the individual imprint sequences at their indicated dates. These problems were more noticeable during this phase of analysis as the confidence in the technique inspired by the phase one analysis certainly lead the author to attempt imprinting on boards that would probably have been rejected during phase one as potentially too problematic.

The 18 board ring sequences, including the inner and outer sections of five boards, were then compared. Eleven crossmatched and were combined to form a 235-year master curve, PCNC-2 (Fig 9; Table 4). The data for this master curve is not presented as it is an interim site master curve that will only be finalised when the analysis has been completed on the samples derived from the full extent of the nave ceiling.

PCNC-2 and the unmatched board ring sequences were tested against the site master from phase one, PCNC-1, as well as an extensive range of dated reference chronologies from the British Isles and elsewhere in Europe. These comprise data-sets dating on average from AD 400 to the present and ranging between Russia and Ireland on an east-west axis and Norway and southern France on a north-south axis. PCNC-2 was dated to the period AD 986-1220 against chronologies derived from material of northern central European origin (Table 5). No reliable results could be obtained for the remaining board ring sequences so these remain undated. Tentative matches were identified for the inner sections of boards **35-I-d**, **33-I-c**, **32-III-i**, **32-IV-cc**, and **32-III-x** but further statistical support is required before these can be accepted. This support may be forthcoming as the analysis proceeds and the site master chronology is strengthened by the inclusion of additional samples. Board **32-III-w** is a composite sequence of three imprints relying on very short overlaps so all three imprint sequences were also tested individually but no consistent results were obtained.

Interpretation

The sapwood estimate applicable is 8-38 at 95% confidence limits (Hillam *et al* 1987). The lowest minimum expected number of sapwood rings is 8 and, in the absence of sapwood, it is this value that has been used to produce a *terminus post quem* for felling for each board (Fig 9). If there are unmeasured outer rings on a board then these are taken into account when calculating the *terminus post quem* for felling. The quality of the intra-site crossmatching, as well as the visual characteristics, suggests that all eleven dated boards form a single contemporaneous group. The outermost measured ring of the board group dates to AD 1220. This is on board **29-IV-k** but there are an additional two unmeasured outer rings. Consequently the boards were all therefore probably felled and primarily used after AD 1230.

Discussion

This is an interim report and it is therefore intended that the following discussion raises a number of issues that will be placed in context and considered in more detail when the analysis has been extended to incorporate boards from the full length of the nave ceiling.

Conifers

The results of the wood type identification indicate the presence of at least two different species. From the observation of the paint only one of the boards analysed, a type A identification, was thought to date from the AD 1740s intervention. This either suggests that the same wood types were used in both major interventions or alternatively that the grouping of the boards through observation of the paint is unreliable. The eighteenth-century refurbishment occurs at a time when Scandinavian imports dominated the timber trade whereas by the early- to mid-nineteenth century North America had become the major supplier, though the Baltic and Scandinavian region were still of importance, particularly for quality or specialist timber (eg Dollinger 1970; Lower 1973; Fedorowicz 1980). The possibility of differentiation between European and North American species is being investigated further but as North American conifer species had been introduced to Europe as early as the eighteenth century this still may not provide any positive information to assist with the dating of the boards to either the AD 1740s or AD 1830s interventions. Although at this stage the identification work does not appear to have provided positive evidence for the dating of the boards, the presence of two wood types may be significant as the four type B boards, the easternmost of those sampled, are from an area of the ceiling in which a number of differences in the interventions have been noted (Lithgow pers comm.). Further wood type identification will attempt to ensure that the sampling strategy incorporates a similar number of boards thought to be from both interventions, though this aim will be potentially hampered by the strict limitations imposed by access.

The dendrochronological analysis of conifers in this country is under investigation. It is the subject of research project, funded by English Heritage, attempting to determine the potential of dating and provenancing of imported conifer timbers in England (Groves 1997; Groves and Boswijk 1998; Groves forthcoming (a); Groves forthcoming (b)). The primary aim is to extend the scope of British dendrochronology so as to enable precise dating evidence to be obtained from a wider range of timber species and hence provide a more comprehensive dating system for timber structures and artefacts. An important secondary aim is that the 'dendro-provenancing' of timber will enhance our knowledge of timber trading during the medieval and post-medieval/early modern periods. In addition the project may reveal information concerning the production and utilisation of timber from non-native species grown in England thereby enhancing our understanding of the history of forestry.

The dendrochronological analysis of conifers in this country is clearly in its infancy and any sites investigated require extensive sampling programmes. As with the oak boards some of the cross-sectional surfaces of the conifer boards are visible and accessible but it is not possible to employ the 'FIMO' technique used for the oak boards. This is because of basic anatomical differences between oaks and conifers. The growth rings of both oak and conifers consist of earlywood, laid down in spring, and latewood, laid down in summer. However the earlywood of oak has large vessels (eg Schweingruber 1990, 400) which, although they become partially in-filled with tyloses, remain sufficiently open for the 'FIMO' to enter them allowing an imprint to be obtained on which the start of a new growth ring is clearly visible. The conifers do not have such vessels (eg Schweingruber 1990, 128) and the 'FIMO' has nothing to imprint. Consequently it will be necessary to consider other techniques which could be employed if dendrochronological analysis of the conifers is to proceed. The ideal method in terms of purely dendrochronological concerns would be to either remove cross-sectional slices from boards which extended beyond the ashlar boards or for various boards to be temporarily removed from the ceiling. However, not only would this type of sampling be by its very nature severely restricted, such major intervention clearly has significant implications for the conservation programme as a whole. As far as minimal intervention techniques are concerned the use of photography is clearly a possibility. This will have to explored during the phase three analysis, looking at practical issues from both a dendrochronological and photographic perspective.

Oaks

A further 11 boards have been dated from the nave ceiling and, in the absence of sapwood, the strict dendrochronological interpretation is that this group were felled and used after AD 1230, as compared to the felling date of after AD 1228 from phase one. The lack of sapwood on the boards reduces the precision of the dendrochronological interpretation. As the dendrochronological program progresses it may be possible to improve the current interpretation and produce a felling date range instead of just a *terminus post quem* for felling. In order to achieve this it remains a priority to locate some boards with traces of sapwood or the heartwood-sapwood boundary. However no boards, sampled or rejected, in either phase one or two of the analysis were located with any traces of sapwood and if these are representative of the entire oak board assemblage then this may not be achieved. In this worst case scenario, as long as the analysed assemblage is sufficiently large, it may still be possible to estimate a felling date range by taking into account other factors, such as the variation in end dates, as was accomplished at Bowhill (Groves forthcoming (c)). The relationship of the felling date to the initial use of the boards relies on evidence from previous studies of panels and panel paintings of known date. These studies imply that very little heartwood would be removed during the manufacture of the panel from the raw timber and the period of time taken for transport, storage, and manufacture, either prior to or after importation, appears to be minimal (eg Fletcher 1980; Lavier and Lambert 1996; Tyers 1998a). Consequently the date of use of the boards is likely to be within the same period as the felling date range, with the slight possibility that, if the boards had the maximum expected number of sapwood rings, the usage date could be a few years after the latest possible felling year.

The results from this group of boards raise the possibility that there could be two phases of boards (Fig 9): the outermost rings of the first apparent group date to the mid-twelfth century, whilst those of the second group date to the early- or mid-thirteenth century. The 'early' group could be contemporary with the structural timbers of the nave roof, though this would imply that boarding was brought onto site for some purpose prior to the construction of the extant ceiling. This seems highly unlikely particularly when taking into account the quality of intra-site crossmatching which suggests that this is a coherent single-phase board group (Tables 4 and 6). The implication is that some of the boards represent the inner heartwood sections of larger trees, whilst others represent the outer sections of the heartwood. This aspect of timber conversion may be addressed in more detail when the subsequent phases of analysis of the oak boards are completed as the conservation programme progresses westwards along the nave ceiling.

The degree of similarity, as indicated by *t* values, of the ring sequences from the individual boards is good (Tables 4 and 6) and provides further support to the suggestion made in phase one that the trees used to produce the boards were derived from a single common woodland. It is hoped that this assumption will be substantiated as more boards are analysed. The site master chronology PCNC-2 has been dated against reference chronologies from northern central Europe, rather than with chronologies from further west in the British Isles or France (Table 5). PCNC-2, like PCNC-1, matches particularly well with chronologies from northern Germany and Denmark which suggests that the source of the timber is likely to be within this region.

Documentary sources indicate that timber was deliberately exported through organised routes as early as the thirteenth century (Simpson pers comm). Timber, in the form of oak planking, was extensively exported from the eastern Baltic region primarily through the German Hanse from the early-fourteenth century until around AD 1650. Extensive documentary evidence in customs accounts (Dollinger 1970; Fedorowicz 1980; Clarke 1992), buildings accounts (Salzman 1952, 206), and the detailed records from the Danish Books of the Sound Dues (eg Bonde *et al* 1997) indicates its importance as a raw material. The advances in dendrochronology over the last decade have seen the development and exchange of the large network of oak chronologies covering northern Europe. This has allowed oak timbers exported significant distances away from their source region to be dated and has had the added bonus of identifying the geographical region from which they were derived (Bonde and Jensen 1995; Bonde *et al* 1997). This increasingly large body of data is currently dominated by groups of timbers imported into various parts of north-west Europe, probably from the eastern Baltic region (Baillie 1984; Wazny 1990; Bonde *et al* 1997). In Britain dendrochronology has identified eastern Baltic boards used for panel paintings, coffins, boat planking, barrel staves, wall and ceiling panelling, doors, altars, and decorative screens. Documentary evidence indicates its importation all down the eastern seaboard of both England and Scotland, and round the south and west coast of England as far as Bristol (Simpson pers comm). Dendrochronological evidence has demonstrated the presence of such eastern Baltic imports at various locations in England and Scotland, ranging from east coast ports as far north as Aberdeen, locations further inland, and as far west as Exeter (Groves forthcoming (c); Howard *et al* 1995; Lewis 1995; Mills and Crone 1998; Tyers 1991; 1998a).

The Peterborough nave ceiling boards are however clearly earlier than this period of major export and also appear to be derived from a source lying somewhere between the eastern Baltic region and England. Timbers ranging in date from the mid-eighth century to the late-seventeenth century, thought to be from this more westerly source, have been previously identified dendrochronologically but form a much smaller body of data than that of eastern Baltic imports. These timbers tend to be in the form of barrel staves, either in their primary form or reused in waterfronts or wells, or occasionally panel paintings. However, assuming that the nave ceiling boards analysed so far are representative, then no large deliberately imported assemblage has until now been identified as early as the thirteenth century. The analysis of the Peterborough Cathedral nave ceiling boards therefore raises fundamental issues concerning the pre-Hansa timber trade and the source of the timber prior to the extensive exploitation of woodlands in the eastern Baltic region.

The visual characteristics of the nave ceiling boards indicate that they were derived from slow-grown, long-lived, straight-grained trees. These trees grew in a closed high-canopy environment and were around 300 years old when felled. They are thus very similar in character to the material imported from the eastern Baltic between the fourteenth and mid-seventeenth centuries (Groves 2000, fig 8). However they are also very similar in character to the structural timbers above the ceiling, the majority of which were felled and used in the late-twelfth century, which were derived from local woodland sources (Groves 2000, fig 8; Tyers 1999a). The use of imported boards in the ceiling, probably less than 50 years after the use of locally grown timbers for the structural elements of the roof, may indicate that such high-quality timber was no longer available locally, or that cheap imports had become available during the intervening period, or even that the use of imported timber was perhaps seen as prestigious.

Conclusion

Analysis of the softwood replacement boards has indicated the presence of two wood types but the relevance of these to the two major post-medieval phases of refurbishment is as yet unproven and will therefore be extended into the phase three work. It is however significant that the few type B boards are from an area of the ceiling where a number of differences in interventions were noted during the conservation programme. The assessment has clearly indicated that the conifer boards have the potential for full dendrochronological analysis, which if successful would provide both dating evidence and other information such as variation in provenance of conifers through time. However the sampling issues will have to be carefully addressed during phase three to determine whether analysis is feasible.

The phase two analysis further demonstrates the successful use of 'FIMO' as a reliable method for 'sampling' the nave ceiling oak boards. However with the increased confidence in the technique more problematic boards are likely to be sampled. Some of the initial measurement difficulties may be resolved if additional cross-sectional surface preparation is carried out and further imprints taken. It is therefore important that the sampling of phase three is undertaken as early on in the programme as possible so as to allow initial laboratory analysis to be undertaken whilst the scaffolding is still in place so that any additional sampling deemed necessary can be carried out.

The dating evidence provided currently suggests a construction date in the mid-thirteenth century or later for the painted ceiling but it is hoped that it will be possible to refine this interpretation as the analysis progresses and incorporates more samples. At present the date of *c* AD 1220-40 proposed by both Binski (pers comm) and Mackreth (pers comm) compares favourably with the dendro-chronological evidence. The identification of a potentially large assemblage of deliberately imported timbers in the mid-thirteenth century is exciting, as is the suggestion that they are of north German origin rather than from further east like the bulk of the dendrochronologically proven imported material.

Acknowledgements

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Figure 1: Map showing the general location of Peterborough Cathedral, Peterborough, based upon the Ordnance Survey 1:50000 map with permission of The Controller of Her Majesty's Stationary Office, ©Crown Copyright

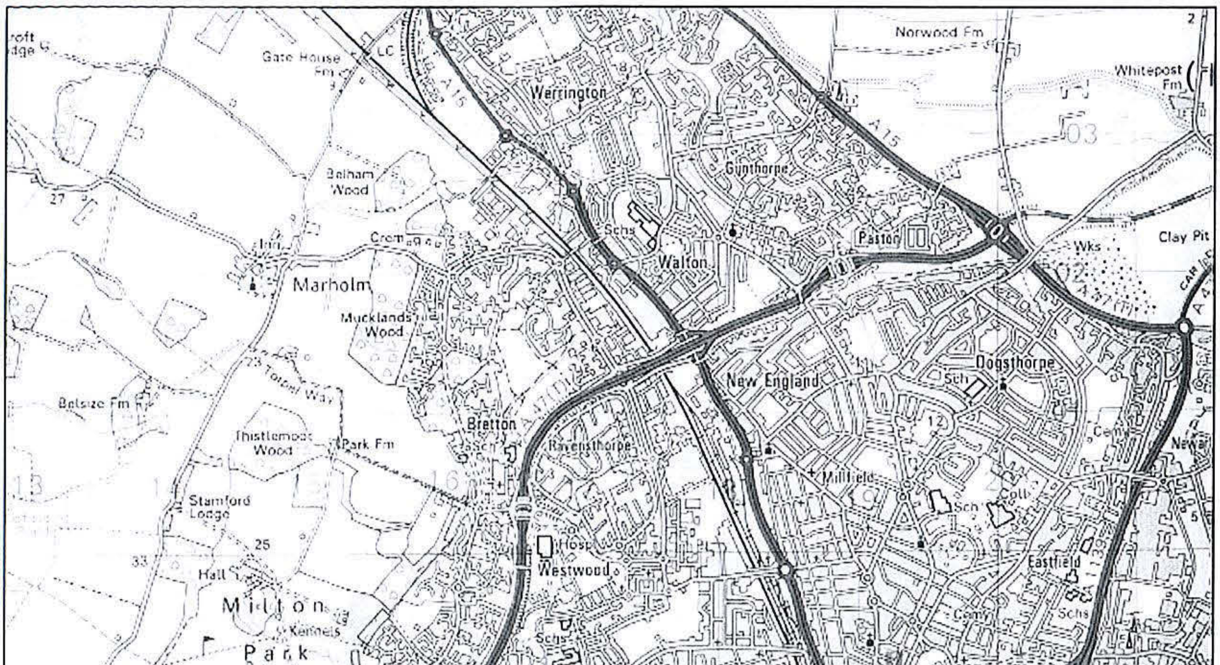

Figure 2: Plan of the cathedral showing the nave

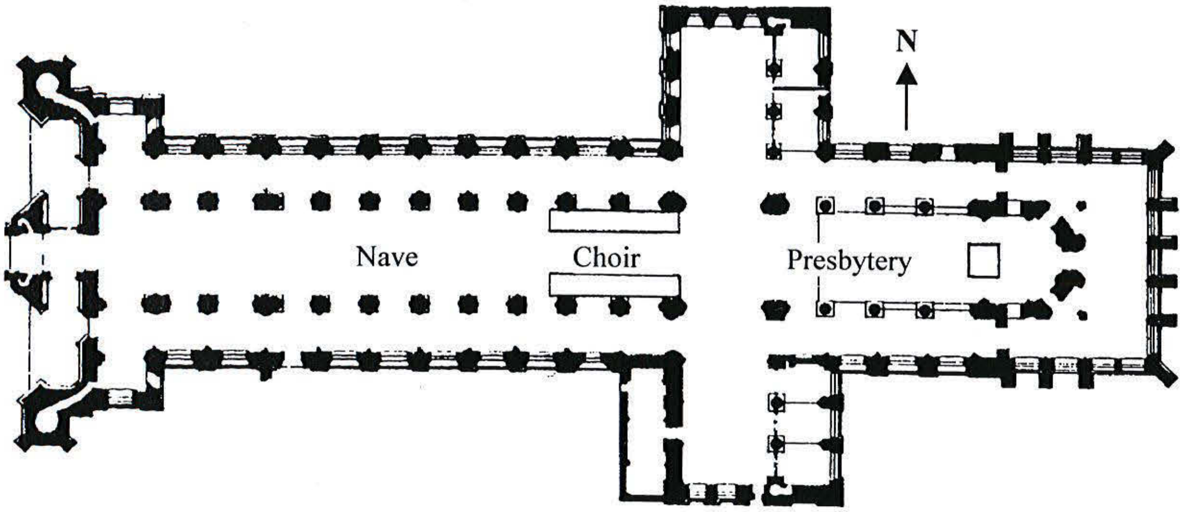

Figure 3: Plan of the ceiling from above showing the original trusses, bay divisions, and the diamond layout of the painted panels (after Bush 1997; Tyers 1999a)

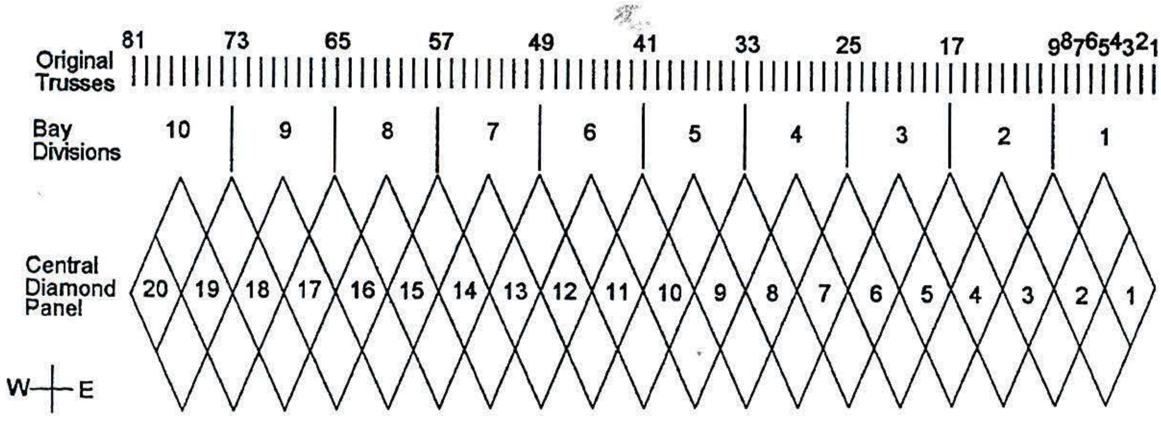

Figure 4: Plan of the ceiling from below highlighting the bay divisions and the location of panels 28/I to 35/IV

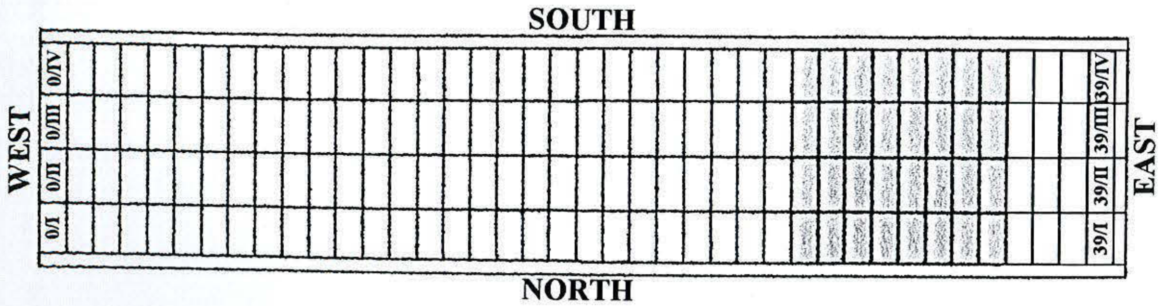

Figure 5: Plan from above showing panels 28/I - 35/IV and the location of the sampled softwood boards
• type A (*Pinus sylvestris* group); • type B (*Picea/Larix* group)

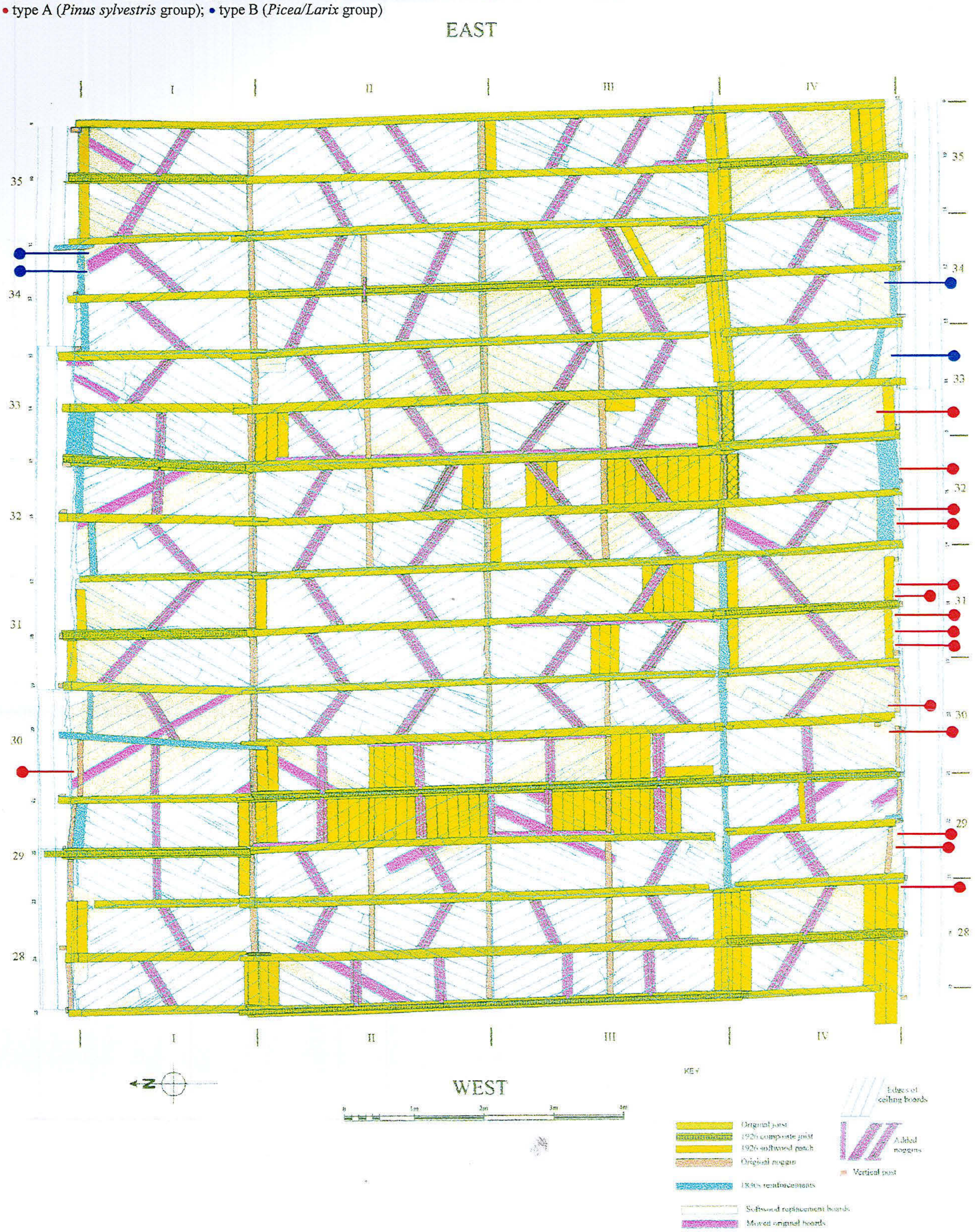

Figure 6: Plan from <u>above</u> showing panels 28/I - 35/IV and the location of the sampled oak boards
• dated; • undated

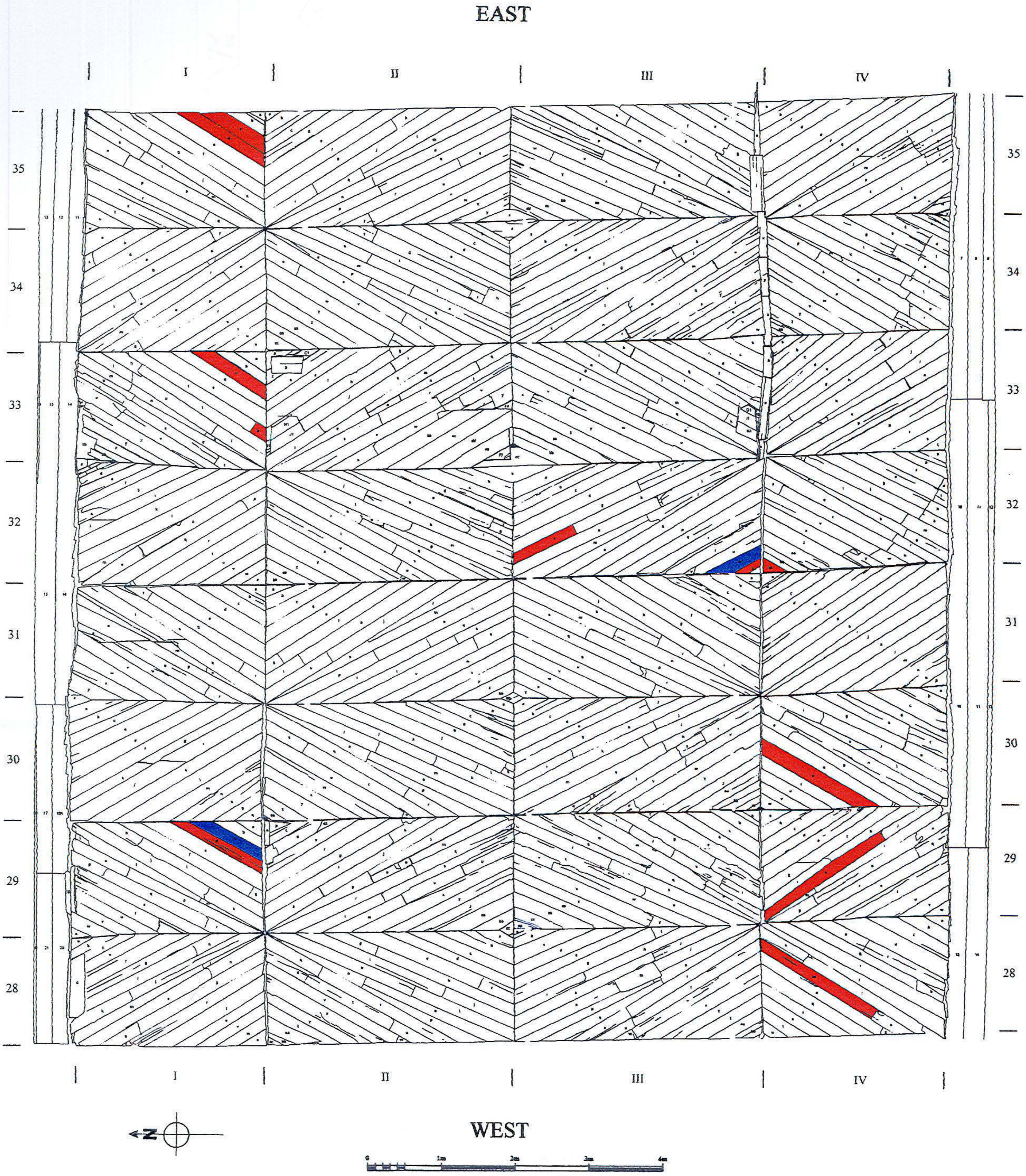

Figure 7a: Diagram showing the relative positions of the matched ring sequences from the individual imprints of board **35-I-d** inner section

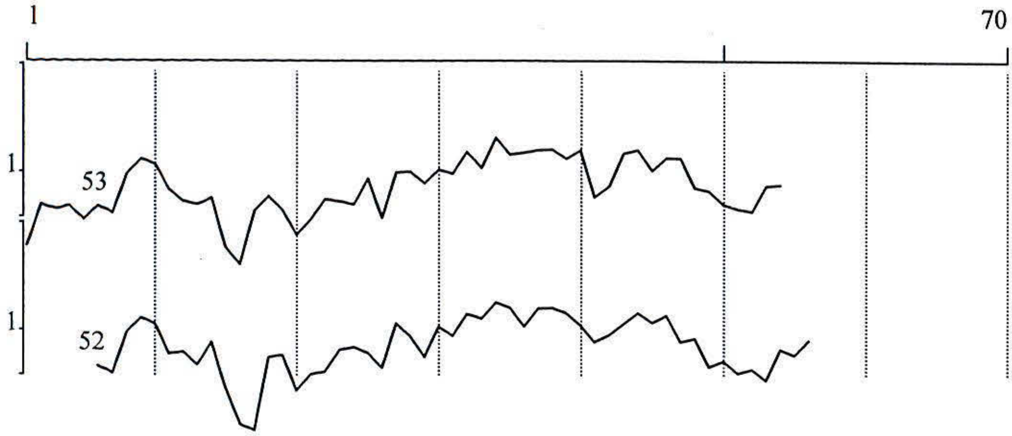

Figure 7b: Diagram showing the relative positions of the matched ring sequences from the individual imprints of board **35-I-d** outer section

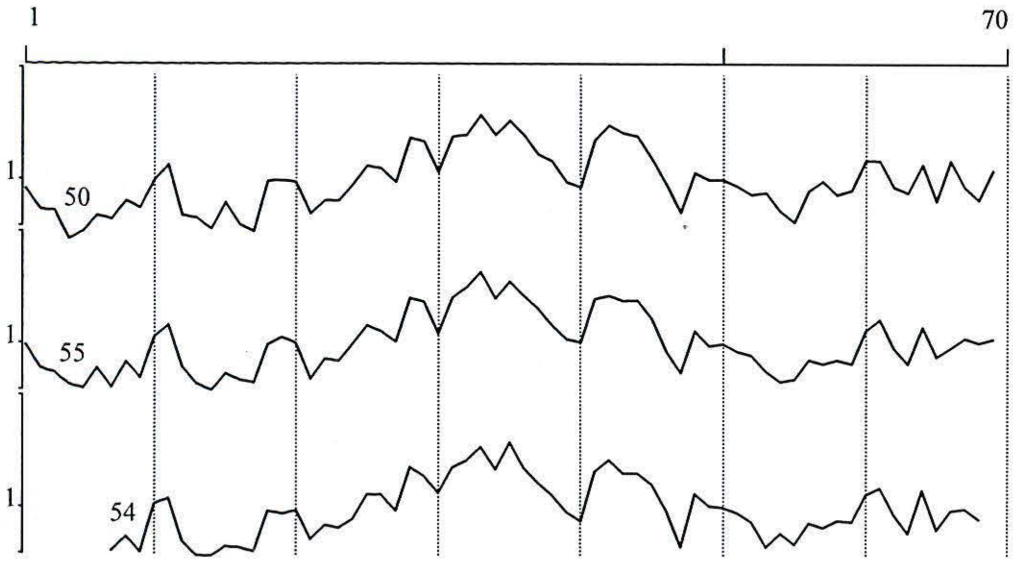

Figure 7c: Diagram showing the relative positions of the matched ring sequences from the individual imprints of board **35-I-c**

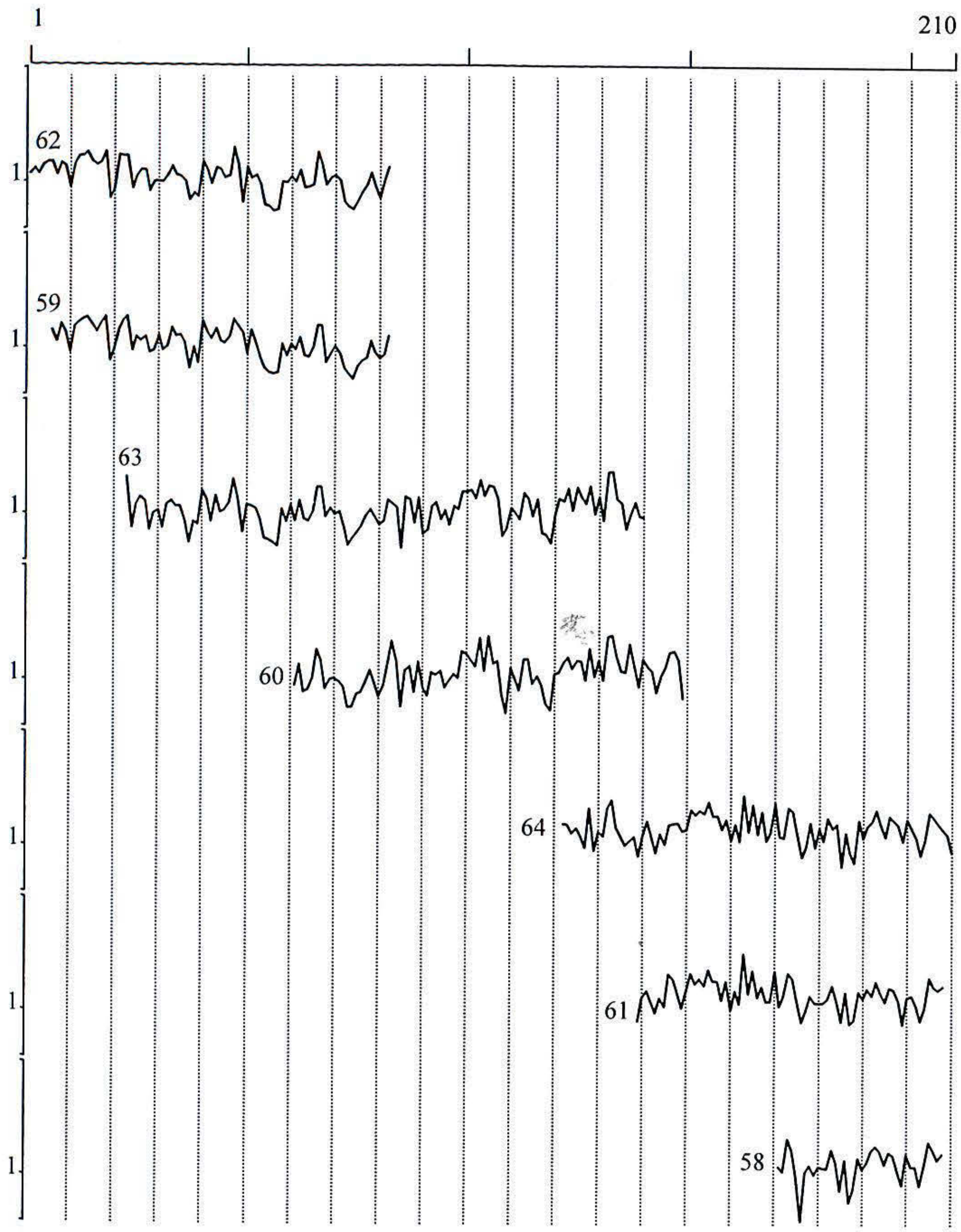

Figure 7d: Diagram showing the relative positions of the matched ring sequences from the individual imprints of board **33-I-c** inner section

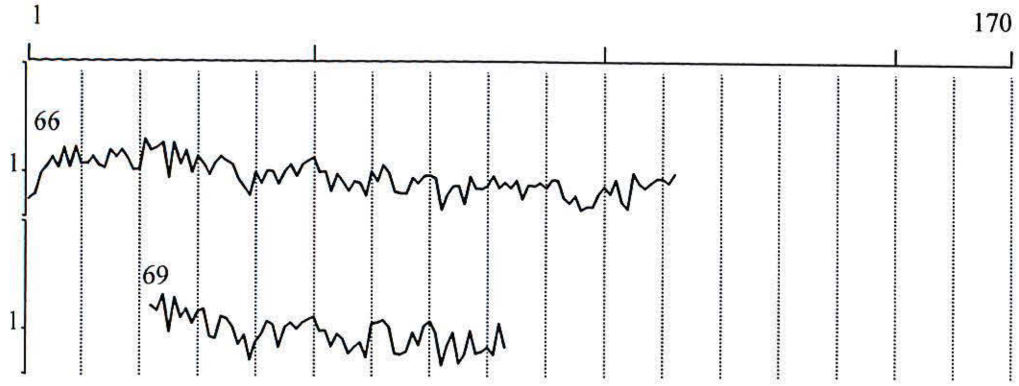

Figure 7e: Diagram showing the relative positions of the matched ring sequences from the individual imprints of board **33-I-c** outer section

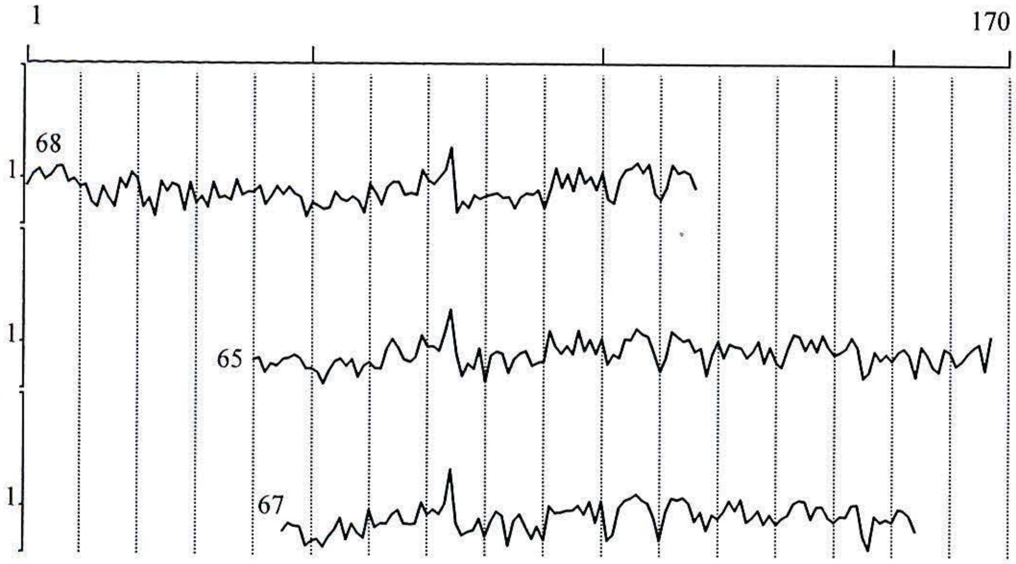

Figure 7f: Diagram showing the relative positions of the matched ring sequences from the individual imprints of board **33-I-g**

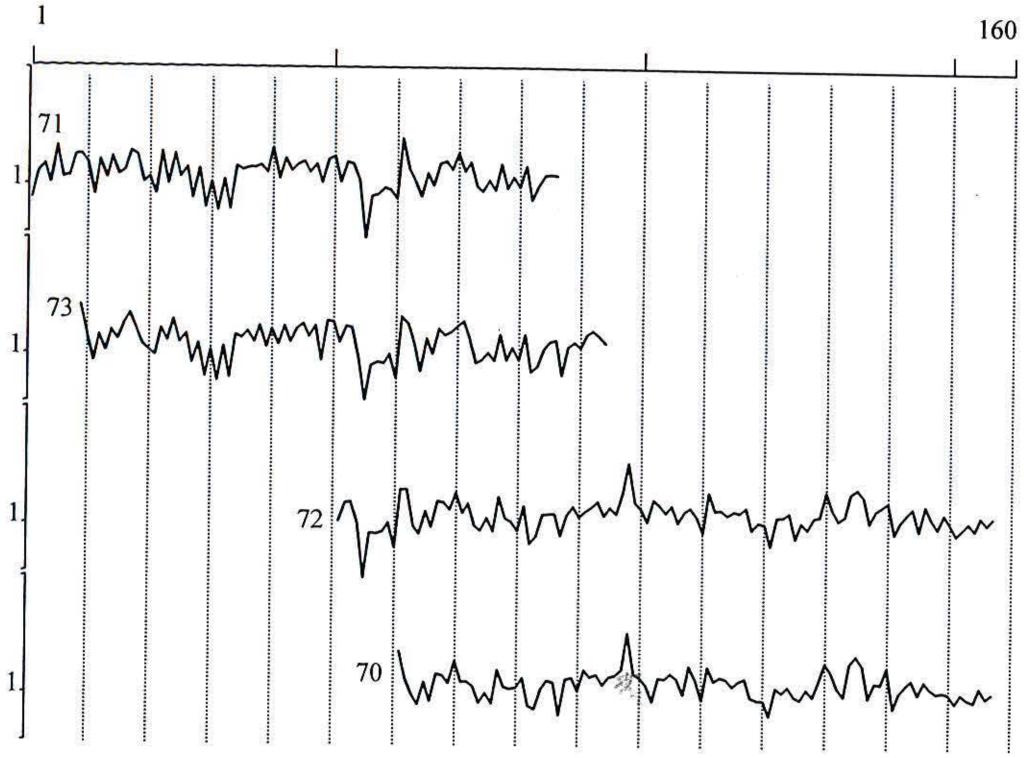

Figure 7g: Diagram showing the relative positions of the matched ring sequences from the individual imprints of board **29-I-c**

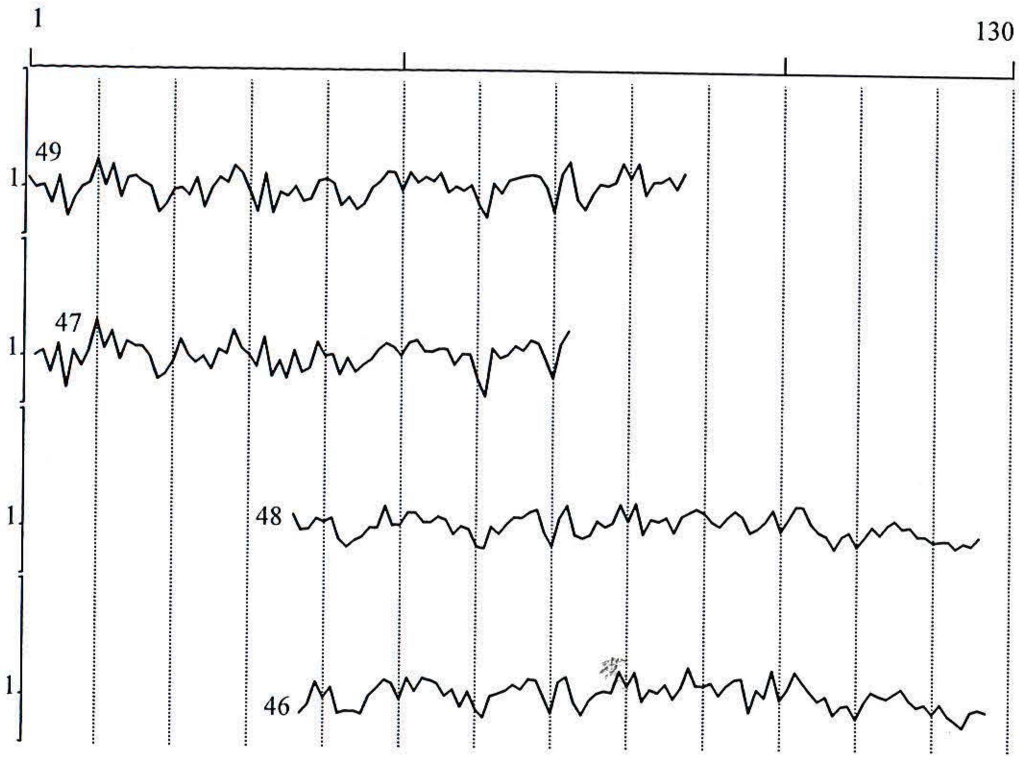

Figure 7h: Diagram showing the relative positions of the matched ring sequences from the individual imprints of board **29-I-d**

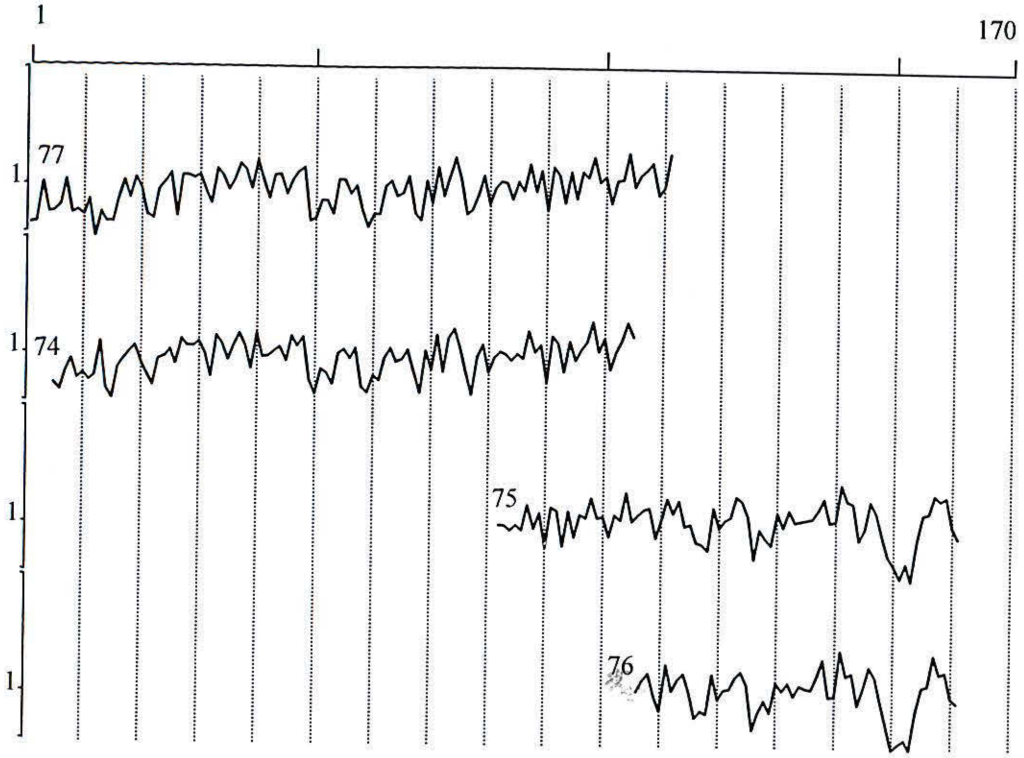

Figure 7i: Diagram showing the relative positions of the matched ring sequences from the individual imprints of board **32-III-i** inner section

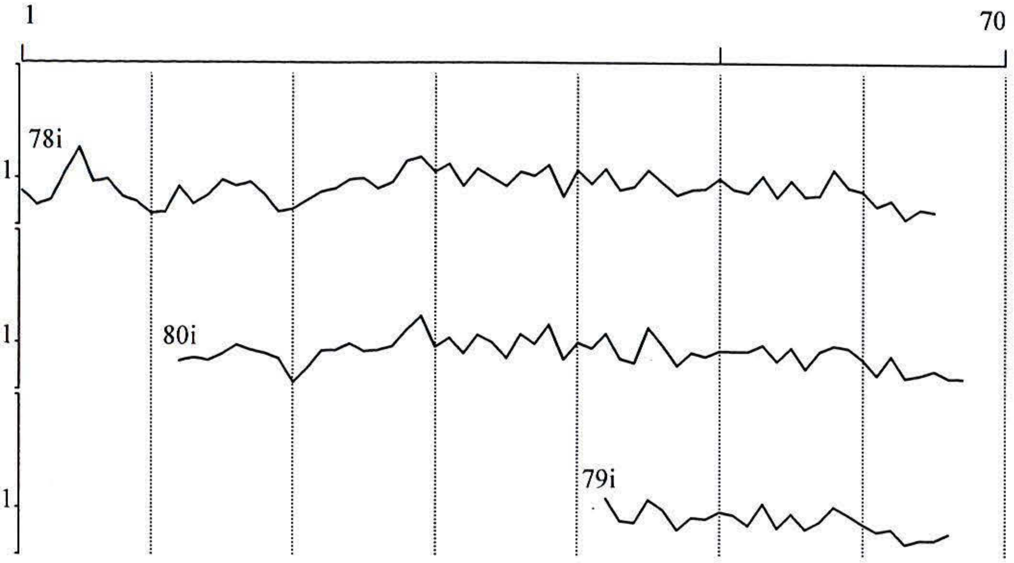

Figure 7j: Diagram showing the relative positions of the matched ring sequences from the individual imprints of board **32-III-i** outer section

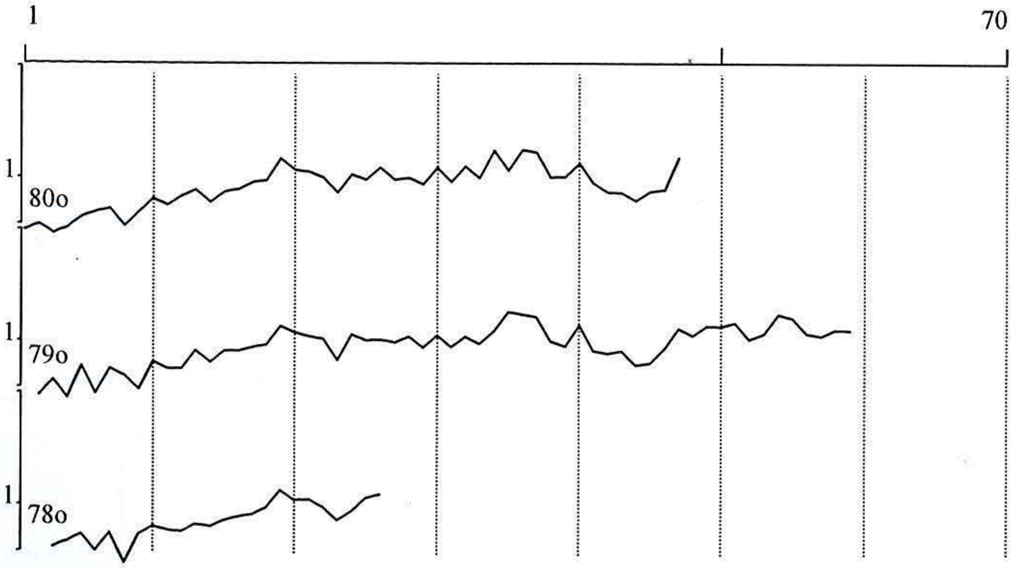

Figure 7k: Diagram showing the relative positions of the matched ring sequences from the individual imprints of board **28-IV-m**

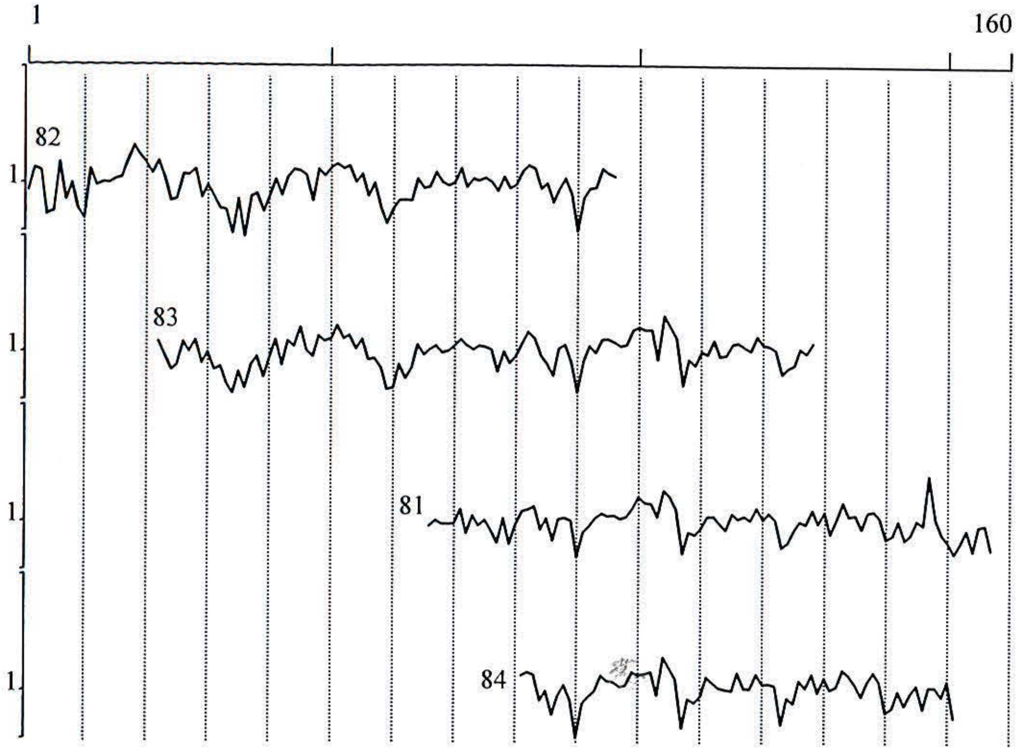

Figure 7l: Diagram showing the relative positions of the matched ring sequences from the individual imprints of board **29-IV-k**

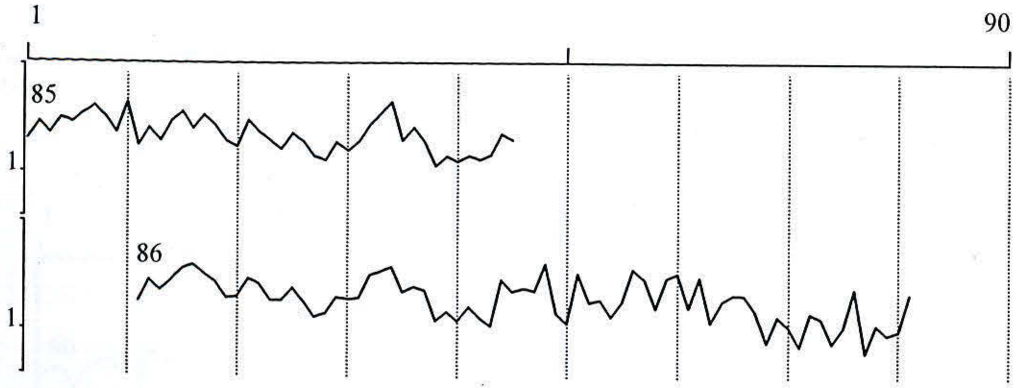

Figure 7m: Diagram showing the relative positions of the matched ring sequences from the individual imprints of board **30-IV-s**

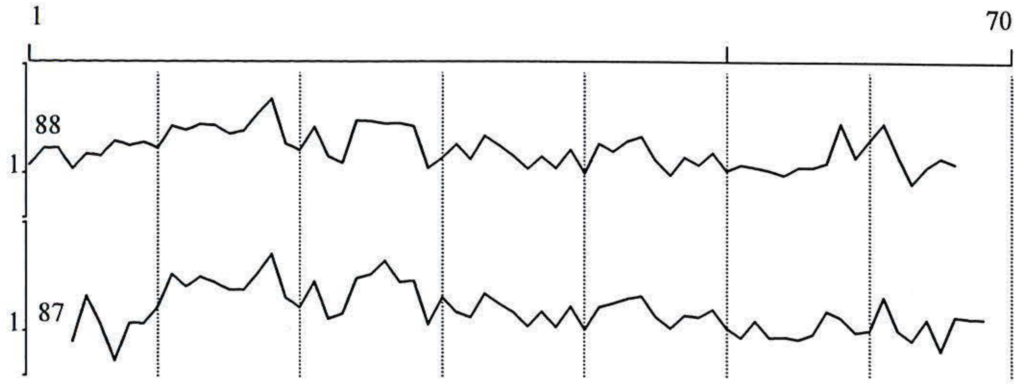

Figure 7n: Diagram showing the ring sequence from the individual imprint of board **32-IV-cc** inner section

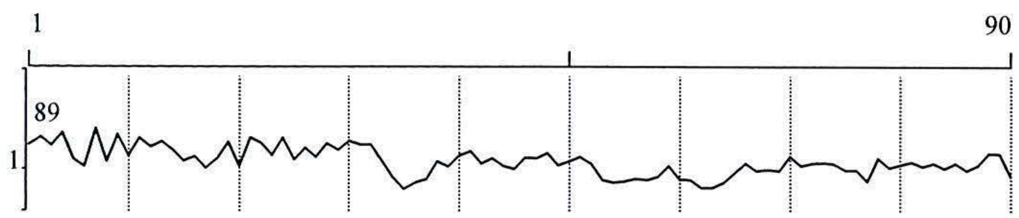

Figure 7o: Diagram showing the ring sequence from the individual imprint of board **32-IV-cc** outer section

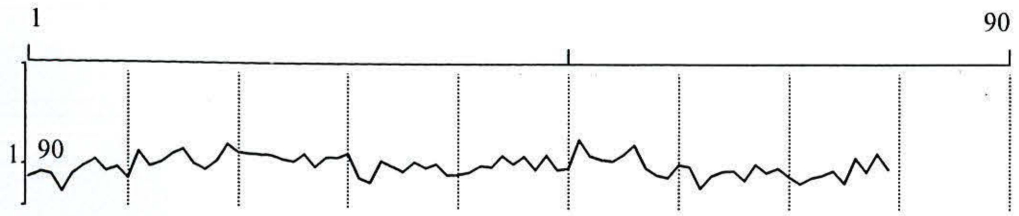

Figure 7p: Diagram showing the relative positions of the matched ring sequences from the individual imprints of board **32-III-x** inner section

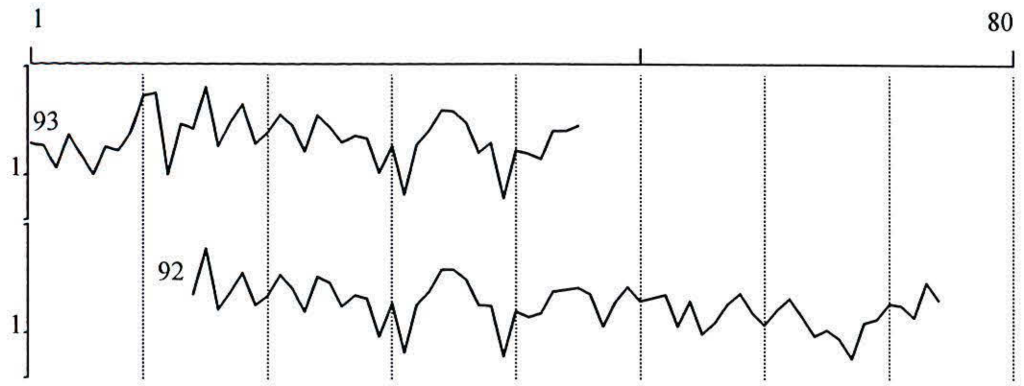

Figure 7q: Diagram showing the ring sequence from the individual imprint of board **32-III-x** outer section

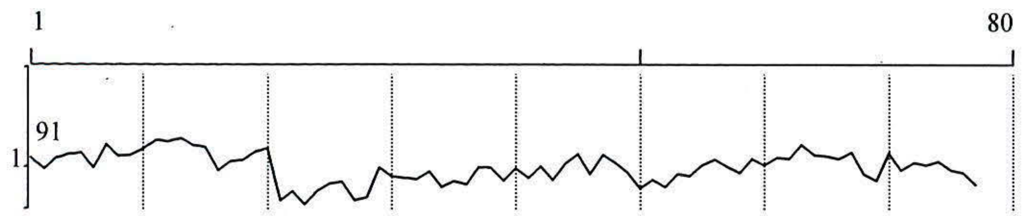

Figure 7r: Diagram showing the relative positions of the matched ring sequences from the individual imprints of board **32-III-w**

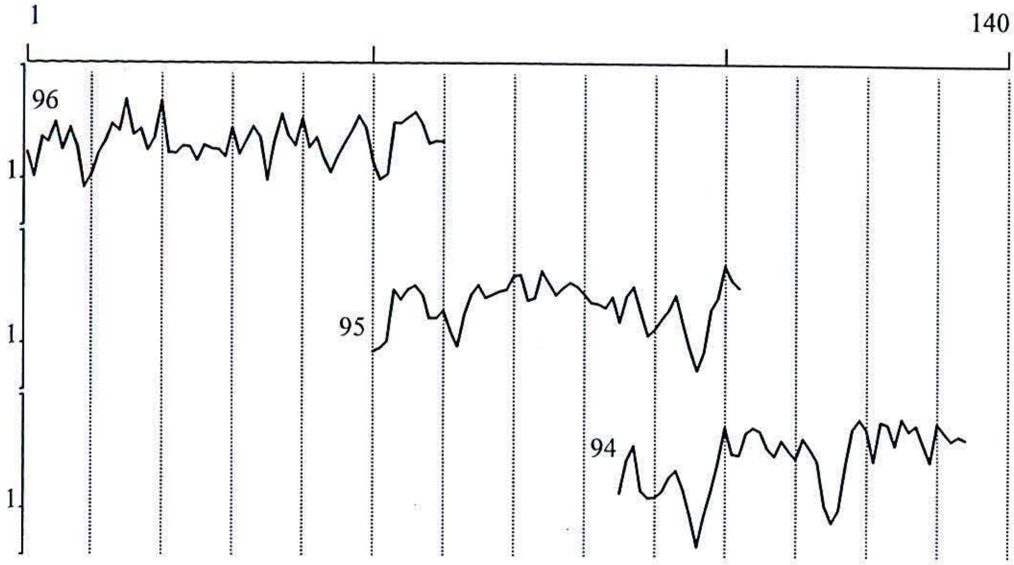

Figure 8: Three imprints from board **32-III-i** showing the position of overlap. Notes made during sampling indicate the length of overlap in millimetres between imprints and visual features on the imprints confirm this prior to actual comparison of the measured ring sequences. Such information, combined with visual comparison of the measured ring sequences, is vital when only short overlaps can be obtained between imprints that cannot be tested using the standard statistical methods employed. The blue box indicates the band of narrow unmeasurable rings which separates inner and outer sets of data for this board

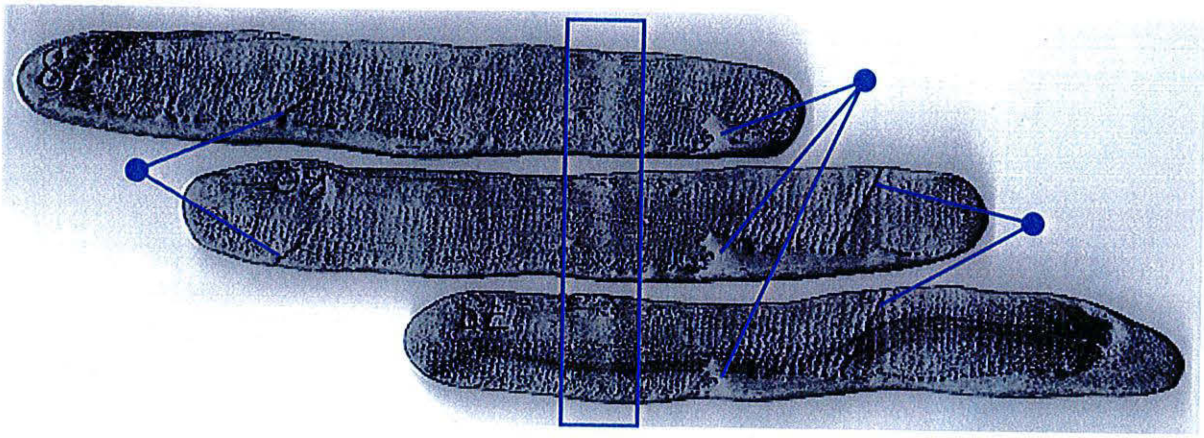

Figure 9: Bar diagram showing the relative positions of the dated board ring sequences from bays 2 and 3 and their associated felling dates

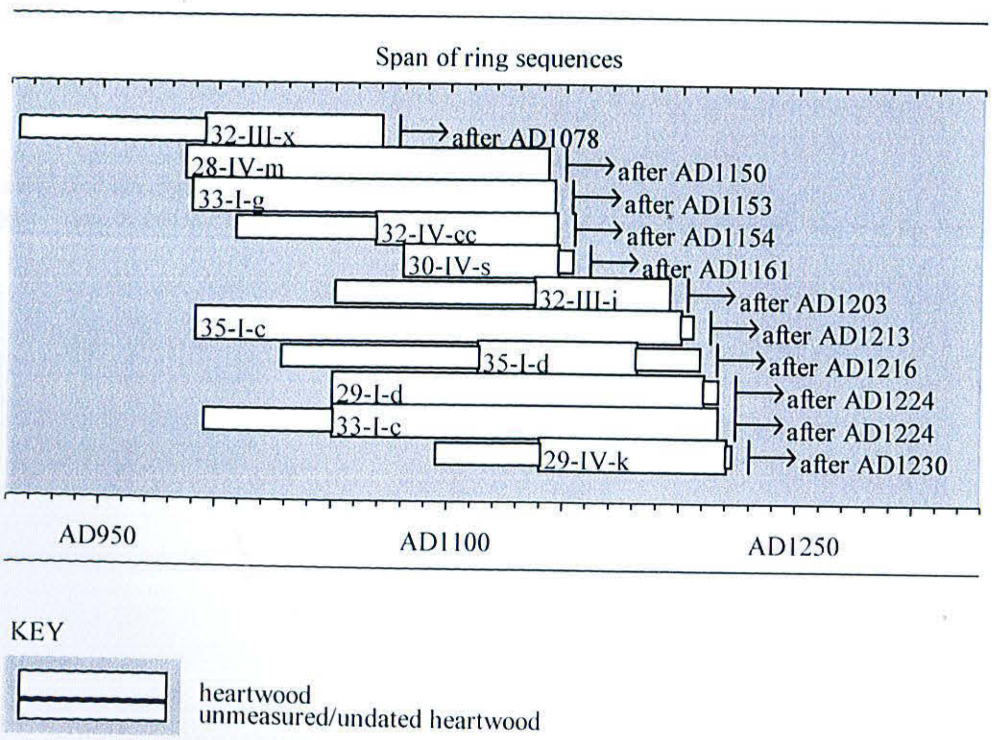

Table 1: Details of the softwood boards from the nave ceiling, Peterborough Cathedral, sampled for wood type identification

Board	AGR	Wood type
30-I-f	2-4	A
34-I-c	>4	B
34-I-a	>4	B
34-IV-j	2-4	B
33-IV-n	2-4	B
32-IV-d	<2	A
32-IV-k	<2	A
32-IV-m	<2	A
31-IV-k	2-4	A
31-IV-l	<2	A
31-IV-m	<2	A
31-IV-n	<2	A
31-IV-o	>4	A
30-IV-d	<2	A
30-IV-h	2-4	A
29-IV-t	<2	A
29-IV-u	>4	A
28-IV-a	>4	A
33-IV-r	<2	A

Board – panel identification number and board identification letter
AGR – estimated average growth rate in millimetres per year
Wood type – type A is the *Pinus sylvestris* group; type B is the *Picea/Larix* group. See text for further details.

Table 2: Details of the oak boards from the nave ceiling, Peterborough Cathedral, sampled for dendrochronological analysis. Where the ring sequences from inner and outer sections of a single board could not be linked details are given for both

Board		Total number of rings	AGR	Cross-section dimensions	Date of measured ring sequence	Comment
35-I-d	inner	*25+* 56	0.83	175 x 15	-	imprints 50-57
	outer	69 *+27*	1.06		AD 1113-1181	
35-I-c		210 *+5*	1.17	210 x 15	AD 991-1200	imprints 58-64
33-I-c	inner	112	0.96	210 x 13	-	imprints 65-69
	outer	167	0.88		AD 1050-1216	
33-I-g		157	1.20	195 x 15	AD 989-1145	imprints 70-73
29-I-c		*81+* 127	1.05	220 x 12	-	imprints 46-49
29-I-d		161 *+6*	1.01	190 x 15	AD 1050-1210	imprints 74-77
32-III-i	inner	67	0.89	190 x 15	-	imprints 78-80
	outer	59	0.98		AD 1137-1195	
28-IV-m		157	1.02	170 x 13	AD 986-1142	imprints 81-84
29-IV-k		*45+* 81 *+2*	1.68	210 x 12	AD 1140-1220	imprints 85 and 86
30-IV-s		68 *+6*	1.42	230 x 14	AD 1080-1147	imprints 87 and 88
32-IV-cc	inner	90	1.16	200 x 12	-	imprints 89 and 90
	outer	79	1.01		AD 1068-1146	
32-III-x	inner	74	1.62	195 x 12	-	imprints 91-93
	outer	77	1.02		AD 994-1070	
32-III-w		134 *+3*	1.95	260 x 14	-	imprints 94-96

Board – panel identification number and board identification letter
Number of rings - total number of measured
nn+ or +*nn* – number of unmeasured rings
AGR - average growth rate in millimetres per year
cross-section dimensions - maximum dimensions of the accessible cross-section in millimetres

Table 3a: Matrix showing the *t* values obtained between the measured imprint ring sequences from board **35-I-d** inner section

Imprint	**53**
52	5.03

Table 3b: Matrix showing the *t* values obtained between the measured imprint ring sequences from the inner section of board **35-I-d** outer section

Imprint	**54**	**55**
50	14.64	16.33
54		21.60

Table 3c: Matrix showing the *t* values obtained between the measured imprint ring sequences from the outer section of board **35-I-c.** \ - overlap is less than 15 years

Imprint	**59**	**60**	**61**	**62**	**63**	**64**
58	\	\	11.82	\	\	9.80
59		8.98	\	11.61	8.53	\
60			\	9.16	12.55	6.19
61				\	\	16.20
62					15.78	\
63						4.92

Table 3d: Matrix showing the *t* values obtained between the measured imprint ring sequences from board **33-I-c** inner section

Imprint	**69**
66	9.23

Table 3e: Matrix showing the *t* values obtained between the measured imprint ring sequences from board **33-I-c** outer section

Imprint	**67**	**68**
65	12.74	7.56
67		9.08

Table 3f: Matrix showing the *t* values obtained between the measured imprint ring sequences from board **33-I-g**

Imprint	**71**	**72**	**73**
70	7.37	14.56	6.92
71		13.35	16.71
72			15.04

Table 3g: Matrix showing the *t* values obtained between the measured imprint ring sequences from board **29-I-c**

Imprint	**47**	**48**	**49**
46	6.15	11.64	14.31
47		7.65	10.84
48			11.22

Table 3h: Matrix showing the *t* values obtained between the measured imprint ring sequences from board **29-I-d**. \ - overlap is less than 15 years

Imprint	**75**	**76**	**77**
74	10.99	\	14.61
75		12.15	21.02
76			\

Table 3i: Matrix showing the *t* values obtained between the measured imprint ring sequences from board **32-III-i** inner section. / - sample less than 30 years

Imprint	**79i**	**80i**
78i	/	8.67
79i		/

Table 3j: Matrix showing the *t* values obtained between the measured imprint ring sequences from board **32-III-i** outer section. / - sample less than 30 years

Imprint	**79o**	**80o**
78o	/	/
79o		4.63

Table 3k: Matrix showing the *t* values obtained between the measured imprint ring sequences from board **28-IV-m.** \ - overlap is less than 15 years

Imprint	**82**	**83**	**84**
81	9.97	12.72	11.11
82		14.21	\
83			13.32

Table 3l: Matrix showing the *t* values obtained between the measured imprint ring sequences from board **29-IV-k**

Imprint	**86**
85	7.12

Table 3m: Matrix showing the *t* values obtained between the measured imprint ring sequences from board **30-IV-s**

Imprint	**88**
87	8.31

Table 3n: Matrix showing the *t* values obtained between the measured imprint ring sequences from board **32-III-x**

Imprint	**93**
92	29.14

Table 3o: Matrix showing the *t* values obtained between the measured imprint ring sequences from board **32-III-w.** \ - overlap is less than 15 years

Imprint	**95**	**96**
94	8.22	\
95		\

Table 4: Matrix showing the *t* values obtained between the matching board ring sequences. - = *t* values less than 3.00; \ = overlap < 15 years

Boards	**35-I-c**	**33-I-c** *o*	**33-I-g**	**29-I-d**	**32-III-i** *o*	**28-IV-m**	**29-IV-k**	**30-IV-s**	**32-IV-cc** *o*	**32-III-x** *o*
35-I-d *o*	6.00	7.14	4.18	6.15	-	-	3.27	3.90	4.50	\
35-I-c		3.19	-	11.91	-	6.06	4.55	4.07	4.18	3.50
33-I-c *o*			-	4.58	-	-	-	3.60	5.94	3.32
33-I-g				3.43	\	3.84	\	-	4.33	3.34
29-I-d					3.34	4.15	4.97	3.89	6.82	-
32-III-i *o*						\	5.02	\	\	\
28-IV-m							\	-	-	3.81
29-IV-k								\	\	\
30-IV-s									3.75	\
32-IV-cc *o*										\

Table 5: Dating the interim site master chronology, PCNC-2. Results of comparisons between some relevant reference chronologies and PCNC-2 at AD 986-1220 inclusive. Some *t* values less than 3.0 are given to demonstrate why it is thought that the nave ceiling boards are imported from northern Germany/Denmark

Region/Group	Reference chronology	*t* value
Germany	Lüneburg (Leuschner pers comm)	10.44
	Niedersachsen Nord (Leuschner pers comm)	10.74
	Niedersachsen Kuestenraum (Leuschner pers comm)	6.41
	Schleswig-Holstein (Eckstein *et al* 1970)	10.72
	South (Becker 1981)	5.29
	Trier region (Hollstein 1980)	7.28
	Weserbergland (Delorme 1972)	7.77
Denmark	Svendborg (Bonde pers comm)	8.61
	West (Bonde pers comm)	8.99
Netherlands	Dordrecht (Jansma 1995)	2.37
	Maastricht (Jansma 1995)	3.92
Poland	East Pomerania (Wazny 1990)	4.59
	Southern Vistula (Krapiec pers comm 1995)	4.10
Sweden	Lund (Bartholin pers comm 1995)	4.93
	West (Brathen pers comm 1983)	2.35
	Mellansverige (Bartholin pers comm)	5.18
France	Paris Basin (Lambert, Lavier, and Bernard pers comm 1994)	1.95
	East (Lambert, Lavier, and Bernard pers comm 1994)	2.65
	West (Lambert, Lavier, and Dourcerain pers comm 1994)	1.55
	Burgundy (Lambert and Lavier pers comm 1994)	2.31
Ireland	Dublin (Baillie 1977a)	3.64
Scotland	South central (Baillie 1977b)	1.84
England	East Midlands 1988 (Laxton and Litton 1988)	5.05
	East Anglia (Tyers, Hillam, and Groves unpubl)	3.15
	South East (Tyers, Hillam, and Groves unpubl)	2.91
	Yorkshire (Tyers, Hillam, and Groves unpubl)	3.99
	North West (Tyers, Hillam, and Groves unpubl)	2.79
	Peterborough Cathedral nave roof (Tyers 1999a)	5.68
Imported	Hull Magistrates Court coffin boards (Tyers 1998b)	5.77
	Millennium Bridge City boards (Tyers 1999b)	4.06
	Fleet Valley - PWB88 C/H (Hibberd 1992)	6.73
	Copper Wreck: boat group (Wazny and Bonde pers comm 1994)	4.21
	Peterborough Cathedral nave ceiling – PCNC-1 (Groves 2000)	15.23

Table 6: Matrix showing the *t* values obtained between the dated boards from phases one and two of the analysis. - = *t* values less than 3.00; \ = overlap < 15 years

Boards	**35-I-d** *o*	**35-I-c**	**33-I-c** *o*	**33-I-g**	**29-I-d**	**32-III-i** *o*	**28-IV-m**	**29-IV-k**	**30-IV-s**	**32-IV-cc** *o*	**32-III-x** *o*
37-I-c	6.27	8.18	5.31	-	7.37	-	-	4.75	3.47	5.45	\
39-I-q	5.58	5.62	4.08	3.29	6.26	-	-	-	4.24	4.42	\
37-IV-b	4.83	5.78	5.36	4.42	7.63	-	-	3.70	-	4.60	\
37-IV-c	5.87	8.72	5.42	6.77	9.55	-	3.35	4.53	3.41	4.28	-
37-IV-h	5.33	3.18	3.50	-	4.33	3.38	\	4.74	-	-	\
37-I-d	-	8.16	3.33	5.48	5.60	\	6.77	\	-	5.69	-
39-II-q	6.15	9.20	6.26	-	10.11	3.99	-	6.17	3.04	4.90	\