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PETERBOROUGH CATHEDRAL, CITY OF PETERBOROUGH, CAMBRIDGESHIRE
TREE-RING ANALYSIS OF THE NAVE CEILING

SCIENTIFIC DATING REPORT

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Summary

Dendrochronological analysis was undertaken between AD 1998 and AD 2003 on oak ceiling boards from the nave in Peterborough Cathedral. This was commissioned by English Heritage and carried out during a programme of cleaning and remedial conservation work. The results indicate a mid-thirteenth century date for the original oak boards throughout the nave ceiling and identify that they were derived from a German woodland source. It was not possible to undertake dendrochronological analysis on the conifer boards used in a series of later repairs, although wood identification analysis indicates they are derived from at least two different types of timber.

Keywords

Dendrochronology

Standing Building

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Introduction

This document is a technical archive report on the tree-ring analysis of oak timbers, and the identification of wood type of conifer timbers, from the nave ceiling of Peterborough Cathedral, City of Peterborough. It is beyond the dendrochronological brief to describe the building in detail or to undertake the production of detailed drawings. Elements of this report may be combined with detailed descriptions, drawings, and other technical reports at some point in the future to form either a comprehensive publication or an archive deposition on the building.

Peterborough Cathedral lies in the centre of Peterborough (NGR TL 194 987), and is now in the Unitary Authority of the City of Peterborough, though traditionally in the Soke of Peterborough, part of Northamptonshire and until recently within the county of Cambridgeshire (Figs 1 and 2). A Benedictine Abbey was established on the site *c* AD 960. The stonework of the present cathedral building, 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 (Figs 3 and 4). An extremely important survival and one of the most notable features of the Cathedral is the wooden nave ceiling which consists of a unique series of painted panels (frontcover). Binski (2003) indicates that it is the largest surviving medieval example of its type in Europe. Its existence is fortuitous as it was constructed as a replacement for stone vaulting that failed. The ceiling was thought to date to the first half of the thirteenth century. Evidence from the decorative elements was taken to suggest a date of *c* AD 1220–40 (Binski 1999), whereas Mackreth's (2004 pers comm) analysis of the structural and documentary evidence suggests that the stone vaulting failed in the AD 1230s, at which time the wooden ceiling was inserted.

The following information about the nave ceiling is mostly summarised from the unpublished reports by The Perry Lithgow Partnership and Hugh Harrison (2003).

Although originally medieval, the ceiling has been the subject of a series of campaigns of restoration and repair. This includes repainting schemes and board replacement programmes, which appear to have used conifer timbers, most notably in the AD 1740s and the AD 1830s. There is no record of the extent of the repairs carried out in the AD 1740s but a number of replacement boards have been identified by paint analysis to be of this date. In contrast, the AD 1830s intervention was far more intrusive. It involved the replacement of many of the original oak boards with conifer boards, as well as the repositioning of both original and AD 1740s boards. The extant ashlar boarding fills the space between the lower edge of the ceiling and the stone wall head and is probably eighteenth or nineteenth century in date.

The ceiling structure consists of 80 cambered horizontal joists, jointed at each end with a halving joint to a sloping joist, originally a scissor brace. Noggins are fixed between the joists using birdsmouth joints to the underside of the joists and nailed. The boards are nailed directly to the underside of the joists and noggins. The ceiling measures 62.2m by 10.7m and is divided into ten bays (Fig 5). Each bay consists of 16 rectangular panels of alternately diagonally set boards forming a series of diamond shapes (Figs 6–15). The two central rows of panels form a flat ceiling with the two outer rows being canted at 45˚. The ceiling boards are laid clinker fashion, whereas the ashlar boarding is laid flush using tongue and groove construction. The original oak ceiling boards are riven and generally tapered in section with a maximum thickness ranging from about 15–22mm, tapering down to less than 10mm. There are two widths of oak board, averaging 175mm and 220mm, although the overlap throughout is approximately 33mm. The full length boards are on average just under 2.1m long, which is just over half of the maximum length of the diagonal across each panel. Overall the number of boards is approximately 3450, of which about 1240 are later replacements.

In the AD 1990s it became clear that the condition of the nave ceiling was deteriorating and posed a potential danger to visitors of the Cathedral. A five year rolling conservation programme was instigated to which English Heritage gave a grant. This was interrupted by an emergency cleaning programme following an arson attempt in the Cathedral during AD 2001. Dendrochronological analysis of the painted boards of the nave ceiling was commissioned at the request of David Heath, the then English Heritage Cathedral Architect, as part of the original conservation programme. The intended purpose of this analysis was to provide independent dating evidence for the primary oak ceiling boards and, if possible, through a comprehensive sampling strategy, to detect any variation in date along the length of the nave. It was hoped that this would confirm the previously accepted dating evidence from documentary sources and other specialist information. In addition it was hoped to determine whether the boards were of local woodland provenance or whether they represented a group of early imported planking.

This report combines into a single narrative all the results of the tree-ring recording and timber identification sampling of the nave ceiling boards and includes results initially reported in Groves (2000a; 2000b). There are two other English Heritage reports on related projects within the Cathedral: Tyers (1999) reports the sampling and analysis of the relict nave roof timbers above the ceiling boards, including the oak joists which the nave ceiling boards are still attached to, along with the analysis of a roof of similar design in the north-west portico; and Tyers (2004b) reports the analyses undertaken throughout the rest of the Cathedral roofs, including the slightly earlier transept ceiling boards undertaken during the remedial

conservation programme in the aftermath of the AD 2001 arson attempt.

Methodology

The tree-ring analysis was undertaken in a series of phases between AD 1998 and AD 2003. Hanging scaffolding, erected below the ceiling, provided access to different sections of the underside, or painted face, of the nave ceiling as the rolling programme of conservation and remedial structural work progressed along its length. Access to the topside of the ceiling was gained from the walkways in the roof space above, though was usually restricted to the area over the scaffolding.

The general methodology and working practises used at the Sheffield Dendrochronology Laboratory follows those described in English Heritage (1998). The following summarises the relevant methodological details used for this project.

Oak boards

The initial dendrochronological assessment of the boards accessed during the first phase of conservation (Bay 1) ascertained that there was suitable material present, and allowed a methodological approach aimed at minimising any necessary intervention to be devised, in consultation with members of the conservation and structural repair teams as well as the Cathedral architect, Julian Limentani. Following its successful application in the first phase, it was used for all subsequent phases of conservation on those oak boards identified during each assessment as suitable and accessible.

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 transverse, or cross-sectional, surface is visible, accessible and can be 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 careful cleaning of 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 was certainly accessible where the joins between sections of panel were not tight, so a series of minimal intervention techniques was considered. The decision was made to initially attempt the most straightforward technique, which had not previously been used in Britain. The exposed cross-sectional surface of each selected board was prepared by a combination of minimal sanding, soft brushes, and compressed air. Preparation was restricted to the back (upper) edge, so as to

avoid paint layers, and was aided by the use of a 'Dremel' with associated sanding and brush accessories. The ring sequence was obtained by taking imprints of the cross-sectional surface of the boards using '*FIMO*', a modelling clay available from art supply stores. This methodology follows the technique of Leuschner and Leuschner (1996). It was found to be most effective to take a series of overlapping imprints from each board. Contemporaneous sampling notes for each board identified the imprint sub-series, and indicated non-overlapping sections and other points critical to the interpretation of the imprints.

After imprinting, the '*FIMO*' strips were heat-hardened to ensure permanence. Some entire imprints, and portions of other imprints, contained ring sequences that could not be reliably resolved. The sequences of growth rings in the imprints containing resolvable sequences were measured to an accuracy of 0.01mm using a purpose-built travelling stage attached to a computer-based measuring system (Tyers 2004a). The resultant 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) 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 and 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), 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 these were then mathematically 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. In this instance the practicalities of acquiring such information were not feasible due to the paint layers and Hessian backing, so any same-tree identification would rely solely on the information produced from the measured tree-ring sequences. 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 tree-ring dates produced by this process initially only date the rings present in the timber. The interpretation of these dates relies upon the nature of the final rings in the sequence. If the sample ends in the heartwood of the original tree, a *terminus post quem (tpq)* 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 are missing. This *tpq* may be many decades prior to the real felling date. 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. The sapwood estimates applied to the German-sourced (see below) oak boards in this report are a minimum of 8 and maximum of 38 annual rings, where these figures indicate the 95% confidence limits of the range. None of the oak boards retain sapwood, so precise felling dates cannot be obtained from this material. The dates obtained by the technique do not by themselves necessarily indicate the date of the structure from which they are derived. It is necessary to incorporate other specialist evidence concerning reuse, seasoning, stockpiling, repair, and (of particular relevance here) transport, before the dendrochronological dates given for the oak boards can be reliably interpreted as reflecting the construction date of the ceiling. As far as the lag between felling and actual use of imported timber is concerned, the evidence from north European oak and conifer imports suggests that usage takes place as little as a few months after felling, and generally within a handful of years, even allowing for the seasoning of panels (Fletcher 1980; Lavier and Lambert 1996; Tyers 1998; Arnold *et al* forthcoming; Simpson pers comm).

Conifer boards and spars

The initial work in Bay 1 focussed on the original oak boards and only once this had proven successful was it decided to attempt to extend the dendrochronological analysis to the later replacement conifer boards. The reasons behind this were two-fold: the conifer boards were considered a potentially valuable source of data for the ongoing English-Heritage-funded research project investigating the viability of dendrochronological analysis of conifer timbers imported into England (Groves 2000c); if successful it would potentially aid the classification of conifer boards, being undertaken during the conservation programme, as belonging to

either the AD 1740s or AD 1830s interventions.

A general assessment was carried out by inspection of the underside of the boards. However, more detailed investigation of individual boards was carried out from above, where the boards in rows I and IV extended beyond the ashlar boards, allowing access to a cross-sectional surface, and also following the lifting of some small sections of protective Hessian from the upper surfaces of the ceiling boards. Exposed conifer backing spars were also assessed. The criteria used during assessment to determine the dendrochronological potential of the conifer boards accessible during the second phase of the site work were the same as those applicable to oak, though, whereas oak can be reliably identified from ordinary visual inspection of its cross-sectional surface, with conifers it is necessary to undertake microscopic analysis of the transverse, tangential, and radial planes. Consequently, in order to identify the type of conifer used, it was necessary to remove a small section of wood, which comprised either a *c* 5–10 mm cube cut from the exposed edge of ceiling boards extending beyond the ashlar boards, or a short core obtained by a 9mm diameter plug cutter, drilled from above. These samples were then thin-sectioned in three planes and mounted on glass microscope slides for examination. The wood type of these slides was determined through reference material in the form of permanent slides, an identification key (Schweingruber 1990), and a computer database (Wheeler *et al* 1986).

The assessment of the conifer boards ascertained that they were suitable wood types and that many contained sufficient numbers of rings for dating purposes. However, extracting these ring sequences proved to be the stumbling block. The cross-sectional surfaces of the conifer boards generally abutted the adjoining panel boards, leaving no access to the cross-sectional surface on the vast majority of boards from below the ceiling. The cross-sectional surface was accessible from above on at least some of the boards that extended beyond the ashlar boards, although many were covered by additional sections of timber or Hessian and they were often cut at an acute angle. It was not possible to employ the '*FIMO*' technique used for the oak boards 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 infilled 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. However, the dendrochronological analysis of musical instruments, such as violins and violas, has demonstrated that it is possible to obtain ring width measurements from the grain showing on radial sections rather than cross-sections of conifers (Topham 1998). In such instances the

grain is highlighted on highly polished and varnished surfaces. Unfortunately, at Peterborough, where small sections of protective Hessian had been lifted, the rougher and unpolished upper surfaces were considered unsuitable. The removal of thin cross-sectional slices from ceiling boards overhanging the ashlar boards was also considered but the acute angle that those accessible were cut at was again problematical. Following consultation with members of the conservation and structural repairs teams and Julian Limentani the overall conclusion was that the necessary intervention to obtain samples suitable for dendrochronological analysis was too great. This, combined with the fact that the results from identification of wood type from Bays 2–6 (second and third phases of site work) proved incapable of providing information useful in separating different phases of conifer repair, led to the abandonment of any further work on the conifer boards in the nave ceiling.

Results and Interpretation

The study of the ceiling boards took place in five phases, spread over a period of six years, as the scaffolding associated with the conservation programme moved westwards along the ceiling, allowing access. This report combines the results from all of the five separate phases of analysis and replaces the two earlier reports on the nave ceiling (Groves 2000a; 2000b). The nomenclature used throughout this report follows that of Donald Mackreth, Cathedral Archaeologist, and The Perry Lithgow Partnership. All boards in this report are therefore referred to using the conservation project's labelling scheme of the form row-column-board (outlined in Fig 5, and separately visible on Figs 6–15; these produce board labels such as 2-III-x and 39-1-q). All tables are ordered from east–west, ie from Bay 1 to Bay 10.

In total there were 77 oak boards from which '*FIMO*' imprint series were attempted, and 60 conifer boards and four conifer structural timbers were sampled for identification purposes. The oak and conifer results are discussed separately below.

Oak boards

A total of 77 oak boards were selected as most suitable for '*FIMO*' imprints. Figures 6–15 indicate the location of these boards within the ceiling. A much larger number of boards was examined and rejected for '*FIMO*' imprinting, for various reasons: the cross-sectional surface was either wholly or partially inaccessible due to surrounding boards; the cross-sectional surface was too damaged to obtain a ring sequence of sufficient length; the ring sequence contained clearly irresolvable bands of narrow rings; or the board contained too few rings for reliable dating purposes. This resulted in the number of boards included in the analysis from each bay being highly variable.

Separate number sequences were maintained for each individual imprint of '*FIMO*', and for each board. Imprints were numbered **1**–**291** inclusive, and the board series were numbered **1**–**77** inclusive. Table 1 provides a concordance linking the dendrochronological projects imprint and board numbers to the conservation project labelling scheme.

A complete series of '*FIMO*' imprints from one board was unsuitable for measurement (board **77**, 2-III-x). The suitable sections of the remaining imprints were each measured as discussed in the methodology. The sequences from the imprint sets obtained from each individual board were then compared with each other. The overlapping portions were mathematically combined to create composite board sequences. This process created 66 single-board series, and 10 inner and outer pairs of measured sections from boards where the resolvable portions were discontinuous but were each of sufficient length to warrant analysis. Fifty of the final composite series included additional known numbers of unmeasured rings at the start or end of the series, normally because access to the full width of the boards was constrained by the surrounding boards and in some instances by paint layers. Appendix 1 lists the data for the individual board series.

After the final sampling and measurement was completed, all the individual board series were then compared with each other, and from within each bay the cross-matched series were combined to form interim individual Bay chronologies, named PCNBB01 to PCNBB10. The results of the comparison of all cross-matched boards is too unwieldy to reproduce. Instead, a series of intra-bay correlation tables (Tables 2–11), and correlation tables between the individual timbers from a single bay to each of the other bay interim composite series, (Tables 12–21) are produced here. The ten interim bay composite series strongly cross-correlated (Table 22) and these were combined to create a single 287-year site composite named PCNB, constructed from the ring series from 69 separate boards. This final sequence was then compared with dated reference chronologies from throughout the British Isles and northern Europe. A single well-correlated position was identified for the PCNB sequence at AD 944–1230 inclusive. Table 23 shows example correlations for the dated PCNB mean sequence at its identified dating position against independent reference chronologies. Table 1 lists the dates of the 69 successfully dated boards and Figure 16 shows their chronological positions and individual interpretations. The site master chronology produced is extremely well replicated and strongly correlates with reference chronologies from northern central Europe. It matches particularly well with chronologies from northern Germany, which suggests that the boards were derived from trees somewhere in this area.

The series from seven other boards proved undatable. There has thus been no evidence produced about the date and origin of these boards. The failure to date this material does not

necessarily mean that these are different in date and source. The visual characteristics of these boards and their ring sequences are not obviously different from those of the dated boards, nor indeed from those of the undated inner sections of seven otherwise dated boards. Most sites have a number of apparently suitable timbers where the ring sequence has perhaps been subject to some distortion or growth anomalies that render it undatable.

There was no evidence of surviving sapwood on any of the original oak boards, throughout the entire ceiling. Overall from the 69 dated boards there are only seven that were recorded during sampling as being potentially complete to their heartwood/sapwood boundaries, though it must be stressed that the abraded edges hampered definitive recognition of heartwood/sapwood boundary. The dates of these seven possible heartwood/sapwood boundaries are: AD 1207, AD 1208, AD 1211, two at AD 1224, AD 1225, and finally AD 1226. A further five timbers, each clearly consisting entirely of heartwood, have outermost heartwood ring dates between AD 1227 and AD 1230.

The entire dated assemblage is clearly broadly coeval, but the lack of bark edge prevents the dendrochronological analysis ascertaining whether the ceiling is either the product of a single short duration construction event or is the product of a longer period of construction that potentially proceeded along the length of the nave (Figs 16 and 17).

If the former is true then the dendrochronological analysis indicates that construction must have commenced after AD 1238. If the identifications of potential heartwood/sapwood boundaries are correct then the evidence indicates that felling of the timbers occurred before AD 1262, and potentially before AD 1245, with construction following on shortly afterward. Regardless of whether the potential heartwood/sapwood boundaries have been correctly identified, the preponderance of ring sequences ending in the late-twelfth and early-thirteenth centuries implies that during conversion from the original tree, only the sapwood and minimal amounts of heartwood were removed (Fig 16). Thus a mid-thirteenth century date, shortly after AD 1238, could still be suggested for this assemblage, even in the entire absence of any heartwood/sapwood boundaries.

If the latter is true then the dating evidence produced by the dendrochronological analysis becomes somewhat more difficult to interpret. There are dated boards from all ten bays of the ceiling so, although the number of boards from each bay is variable, it is possible to produce combined felling dates for each bay (Fig 17), the underlying assumption being that construction was based on a bay by bay process. The widely differing end-dates of the individual boards in any one bay however suggests that caution should be employed in the interpretation of those bays with fewer dated boards. For example, both the bays with the

earliest possible felling dates are amongst the four bays with the fewest dated boards; Bays 3, 6, 9 and 10 are represented by four or fewer dated boards, whereas all other bays are represented by seven or more dated boards. The implication is that the end dates of the boards in the better-represented bays are likely to provide a more accurate guide to the date of felling. If the combined dates of the bays with four or fewer boards are ignored, then the earliest likely inception date for the ceiling is AD 1228, if it began at the easternmost Bay 1 (Fig 17); work in Bays 4 and 8 cannot have begun before AD 1238. If the heartwood/sapwood boundary identifications are correct, Bay 8 has the earliest possible end date for the felling programme, AD 1245, whilst in contrast Bay 4 could include timbers felled as late as AD 1262. The lack of bark edge clearly severely hampers the positive identification of any small variation in felling date as one proceeds along the nave.

Although it is possible to interpret the individual board felling dates of the entire dated assemblage as suggesting at least three overlapping felling groups (combined felling dates of AD 1219–45 and AD 1234–62 for the two groups of boards with possible heartwood/sapwood boundaries; and after AD 1238 for the five boards with the latest heartwood rings), it must be stressed that there is no statistical evidence of sub-groups within the dated material. This, combined with the level of similarity, as indicated by the *t*-values, of the ring sequences from the dated individual boards across the entire ceiling, suggests that the boards were likely to have been derived from a single common woodland source. It therefore seems likely, particularly as these timbers are imported, that those used in the initial construction of the nave ceiling represent either a single intensive felling period, or a continuous felling campaign spanning a small number of years in the mid-thirteenth century. Short-term stockpiling remains a possibility but in the absence of bark edge the dendrochronological analysis cannot confirm or refute this possibility.

Overall, the dendrochronological analysis therefore indicates that the ceiling utilised timbers felled in the mid-thirteenth century, and that construction was certainly not completed before AD 1238, but was likely to have been completed within a maximum of a quarter of a century, and potentially within a few years, of this date. This accords well with the structural and documentary evidence (Mackreth 2004 pers comm) indicating that the stone vaulting failed in the AD 1230s, at which time the ceiling was inserted, and also implies that it is towards the end, and potentially slightly later, than the *c* AD 1220–40 date range suggested by Binski on the evidence of decorative elements. It should be noted that although the number of dated boards is only just over 3% of the surviving original oak boards and only approximately 2% of the total number of original boards, the sampling was effectively a random process, based on accessibility, so they should be representative of the full original assemblage.

Conifer boards and spars

The assessment of the dendrochronological potential of the conifer ceiling boards, ashlar boards and backing spars indicated that there was a significant number with sufficient rings for analysis. Although they were excluded from dendrochronological analysis due to sampling procedural issues (see above), it was feasible to obtain a series of small samples for wood identification by the methodology discussed above. A total of 60 samples was taken from replacement ceiling boards, the locations of which are indicated in Figures 7–11 and Table 24. Details are also provided in Table 24 of samples from four conifer spars on the backs of the boards. The results indicated the presence of at least two wood types. In neither case was it possible to determine the species of these types as many conifer species have very similar anatomical features. The two types, both conifers in the Pinaceae family, are as follows:

Type A is one or more of *Pinus sylvestris* L. (Scots pine), *P. mugo* Turra (Mountain pine), *P. nigra* Arnold (Black pine) or *P. resinosa* Soland (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 (Weidenhoff pers comm). Forty of the boards, and all four of the backing spars, were assigned to wood type A (Table 24).

Type B is either *Picea* spp. (Spruce) or *Larix* spp. (Larch) or possibly a mixture of both types. 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, whilst it is more gradual in *Picea*, and the heartwood of *Larix* is generally reddish, whilst there is less distinctive heartwood/sapwood differentiation in *Picea*. 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. Twenty boards were assigned to wood type B (Table 24).

Twenty of the boards analysed, all type As, including seven with a frieze underpaint layer, were thought to date from the AD 1740s intervention. The remaining 40 boards, 20 type As and 20 type Bs, were thought to be derived from the AD 1830s intervention. These results suggest that whilst the AD 1740s intervention may be confined to the use of a single wood

type, the AD 1830s intervention uses at least two wood types, one of which is the same as, or at least indistinguishable from, that used in the AD 1740s. Alternatively it could imply that the present assignments of the boards to particular refurbishments on the basis of their paint details are unreliable, but clearly without additional evidence this can be neither confirmed or refuted.

The growth rate of each sample were estimated and categorised into three groups (less 2 mm/year, 2–4 mm/year, or greater than 4mm/year, Table 24). This data is based on the evidence of the small number of visible/sampled rings. The typical age trends in conifer growth (eg Schweingruber 1988, 121) result in samples from the innermost section of the board generally having wider rings than those from the outermost section; consequently, categorisation of the boards is clearly not definitive. However, in general, the type B samples tend to be faster grown than the type A samples.

Discussion

Oak boards

Documentary sources indicate that within Europe timber was deliberately exported through organised routes as early as the twelfth 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 (Clarke 1992; Dollinger 1970; Fedorowicz 1980), 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 two decades 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 the added bonus of identifying the broad 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 from the eastern Baltic region, the area of present day Poland and the countries to the east and north (Baillie 1984; Bonde *et al* 1997; Haneca *et al* 2005; Wazny 1990; Wazny 2002). 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 2002; Lewis 1995;

Mills and Crone 1998; Tyers 1996).

The use of imported boards is therefore not unusual, but the Peterborough Cathedral nave ceiling boards are clearly earlier than the period of major exports from north-eastern European sources, and also are derived from a source lying between the eastern Baltic region and England. Imported timbers ranging in date from the mid-eighth century to the late-seventeenth century from this more westerly source have been previously identified dendrochronologically, but form a much smaller body of data than that of the eastern Baltic imports. These north-west European timbers tend to be in the form of barrel staves, either in their primary form or reused in waterfronts or wells, or for the later period from panel paintings and furniture. However, the analysis of the Peterborough Cathedral nave ceiling boards identifies that this structure contains the largest imported assemblage of boards known from this area for the thirteenth century. Its discovery therefore raises fundamental issues concerning the extent of the pre-Hansa timber trade and the source of the timber prior to the extensive exploitation of woodlands in the eastern Baltic region. Subsequent to the initial Peterborough results being reported, the analysis of timbers of similar date from Salisbury Cathedral identified that both structural elements and boarding there were imported from south-east Ireland (Miles 2002), whilst the analysis of both the doors (Miles and Bridge 2005), and the altar retable (Tyers 2002) from Westminster Abbey reveal that a mixture of local and north-western European sources were routinely in use there during the first half of the thirteenth century.

The nave ceiling boards were derived from slow-grown, long-lived, straight-grained trees. These trees probably grew in a closed high-canopy environment and were generally around 300 years old when felled. They are thus very similar in character to the material imported from the eastern Baltic region between the fourteenth and mid-seventeenth centuries (Groves 2000a, Fig 8). The nave boards are very similar in character to two other groups of timber analysed in Peterborough Cathedral (Groves 2000a, Fig 8). Firstly, the surviving structural timbers above the nave ceiling, the majority of which were felled and used in the late-twelfth century (Tyers 1999). Secondly there are some boards surviving in the north and south transept ceilings which tree-ring analysis has revealed date from AD 1200–25, and AD1203–31 respectively (Tyers 2004b). Both of these groups of timbers are of English origin, though in the case of the latter group not necessarily immediately local sources. The use of imported boards in the nave ceiling, probably no more than 50 years after the use of similar quality locally grown timbers for the structural elements of the nave roof, and probably within a few decades after suitable quality native material was used for the transept ceiling boards, potentially identifies a narrow time window where either high-quality local timber was no longer available, perhaps through over-exploitation, or that cheaper imports had become

readily available, supplanting the local sources. An alternative possibility is that the imported timber was perhaps perceived to be of better quality or that its use was more prestigious.

It is possible that the maximum length (*c* 2.1m) of the boards present in the nave ceiling represents the 'standard' length of the raw imported material, though this is somewhat difficult to determine. Documentary evidence is of little help and the only original sized raw planks known are the early fifteenth century eastern Baltic cargo from the Copper Wreck . The Copper Wreck planks had dimensions of: length 2.2–2.3m; width 240–300mm; thickness 40–65mm (Heymanowski 1979). The nave ceiling boards are therefore of comparable length, but tend to be narrower than these raw planks, from which it may be possible to split two or three boards of similar thickness to the nave ceiling boards. The only visually and statistically likely same-tree pair identified is two boards from Bay 4, boards 27-III-c and 27-IV-b. The overall lack of positive identification of boards derived from the same-tree is perhaps not surprising when one considers that the 69 dated boards represent only 2% of the total number of boards in the original construction.

Conifer boards and spars

The results of the wood type identification did not appear to aid the differentiation between the AD 1740s and AD 1830s replacements. The eighteenth-century refurbishment occurred at a time when Scandinavian imports dominated the timber trade, whilst by the early- to mid-nineteenth century North America had apparently become a major supplier, though the Baltic and Scandinavian regions were still of importance, particularly for quality or specialist timber (eg Dollinger 1970; Fedorowicz 1980; Lower 1973). The differentiation between European and North American species purely on wood anatomical grounds has not proven possible with this material. North American conifer species were introduced to Europe as plantation trees as early as the eighteenth century. It is therefore likely that even if it were found to be possible to distinguish between the types it may not provide any useful information to assist with the dating of the boards to either the AD 1740s or AD 1830s interventions.

Unfortunately, dendrochronological analysis, which may have provided an independent means of distinguishing the boards associated with the major interventions, proved impractical, even though at least some of the nave ceiling conifer boards are visible and accessible The use of *'FIMO'*, the use of photography, the removal of cross-sectional slices from boards which extended beyond the ashlar boards, and even the temporary removal of boards from the ceiling were all considered. The two former methods failed to provide a viable method for the acquisition of reliable tree-ring data, whereas the latter methods were not considered viable within the conservation programme. The dendrochronological analysis of conifers is any event a developing area in this country, so successful dating was by no

means a certainty. As with oak, the primary aim of their analysis is to enable precise dating evidence to be obtained for structures. For conifers an important secondary aim is the identification of the broad region of origin, which in turn has the potential firstly to enhance our understanding of conifer timber trading during the medieval and post-medieval/early modern periods, and secondly may also 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.

Conclusions

The analysis of the oak boards used in the primary construction of the nave ceiling identifies that they appear to post-date the structural alterations to the west end of the nave, interpreted as part of the construction of the new west front and towers, which used timber felled in the AD 1220s (Tyers 1999). The nave ceiling was assembled using timber felled in the mid-thirteenth century. Whilst construction could have commenced a few years earlier, depending on whether the oak boards represent a single intensive felling period or a continuous felling campaign spanning a small number of years, it could not have been completed until after AD 1238. It was however likely to have been completed within a maximum of a quarter of a century, and potentially within a few years, of this date. The dendrochronological dating evidence therefore corroborates that from the analysis of the decorative elements (Binski 1999; 2003) and the documentary and structural evidence (Mackreth 2004 pers comm). Regrettably, the absence of bark edge and lack of any trace of surviving sapwood has prevented the dendrochronological analysis ascertaining whether or not there is a minor variation in date as work proceeds westwards along the length of the nave and whether there was any short-term stockpiling of the boards prior to construction.

The identification of a large assemblage of imported timbers of north German origin in the mid-thirteenth century provides important evidence that, for the eastern part of England, the early stages of an organised intra-European trade in oak boards may have begun with material from northern Germany. In addition this analysis has demonstrated that the use of '*FIMO*' imprinting provides a reliable and unobtrusive method for obtaining tree-ring series from *in-situ* oak boards, such as those in the Peterborough nave ceiling.

It has not been possible to provide any independent dating evidence for the conifer boards used in the AD 1740s and AD 1830s interventions, either through dendrochronological analysis or species identification. Analysis of the wood types of the conifer replacement boards indicated the presence of at least two types, whose distribution does not reflect the refurbishment phases to which they had been assigned. This material has potential for dendrochronological analysis, but it proved impossible to recover reliable ring series from this

material using a low intervention method in accordance with the conservation programme. Their analysis may have provided dating evidence and information relating to variation in provenance of different conifer types through time, as some of the previous analyses of conifer timbers have demonstrated (Groves 2000c). In addition, it may have allowed independent verification of their assignment to specific refurbishment programmes on the basis of their paint and other factors.

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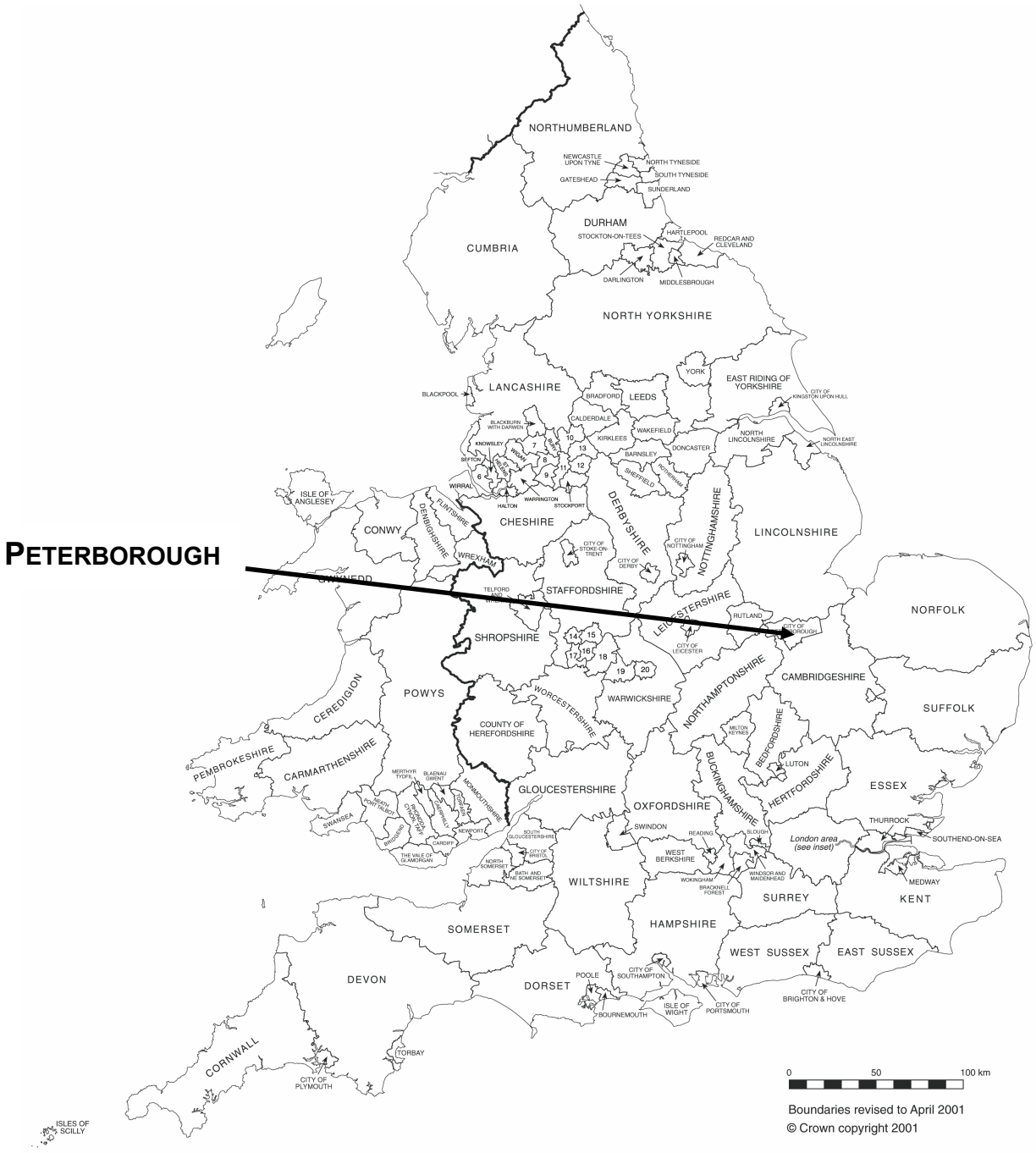

Figure 1 Location of Peterborough within England and Wales.

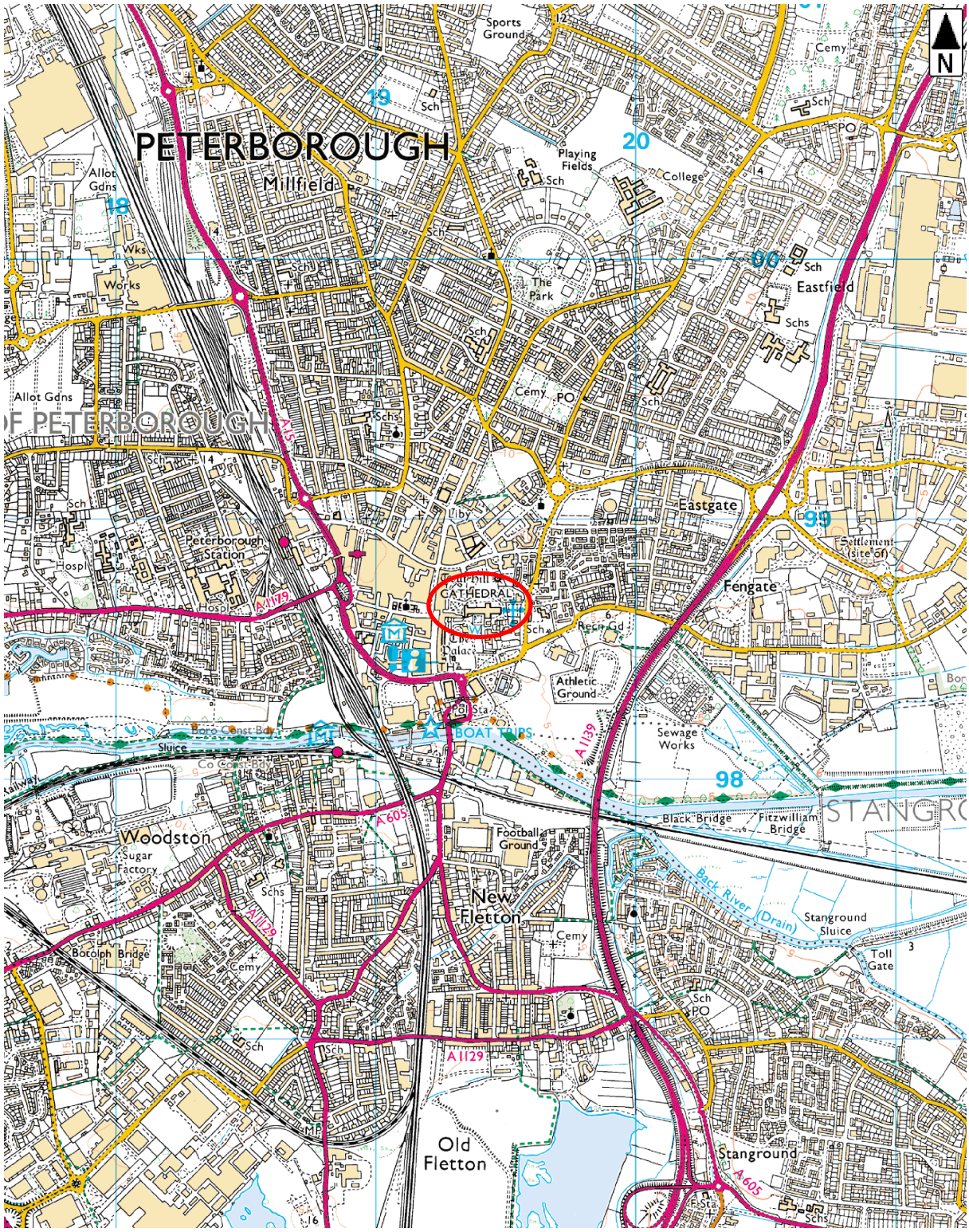

Figure 2 Location of Peterborough Cathedral.

Figure 3 Photograph of the west front of Peterborough Cathedral (photo: John Critchley)

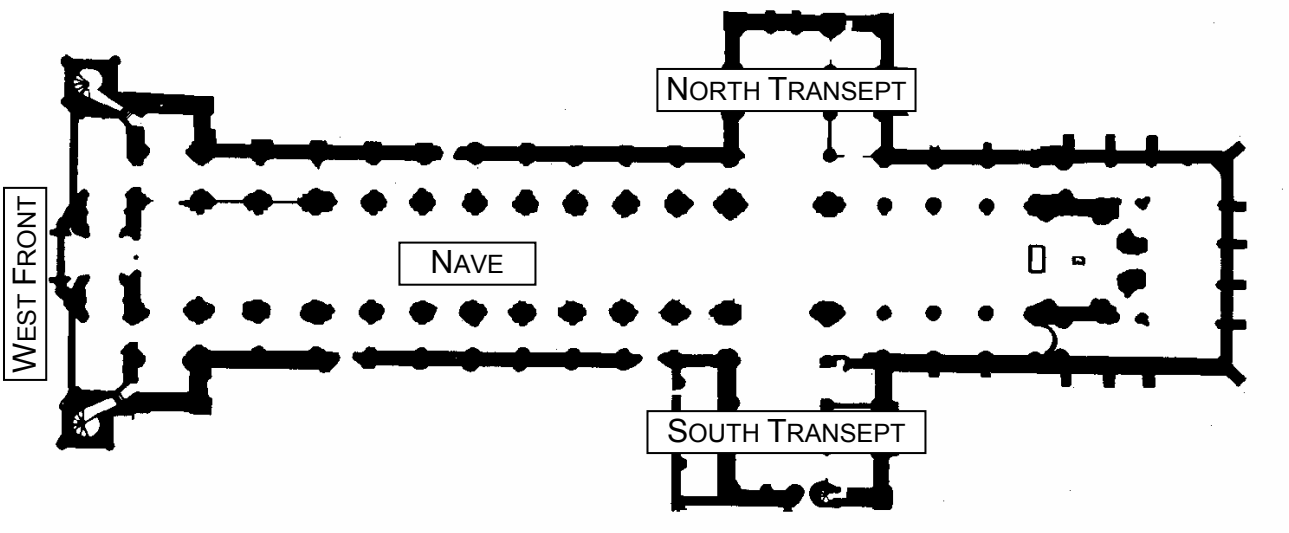

Figure 4 Plan of Peterborough Cathedral showing the location of the nave and other areas mentioned in this report

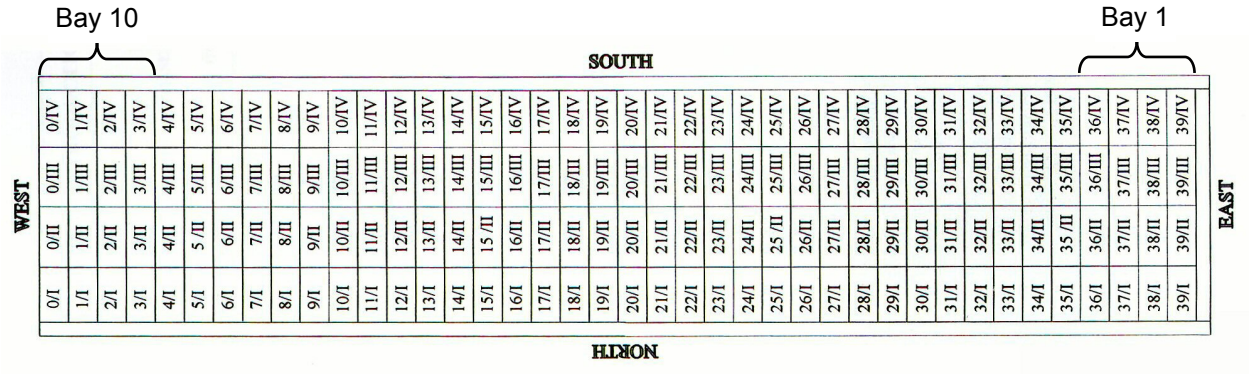

Figure 5 Plan of the nave ceiling from below showing the row/panel labelling scheme (after The Perry Lithgow Partnership and Hugh Harrison 2003). The Bays are numbered from the east, each comprising four columns of panels

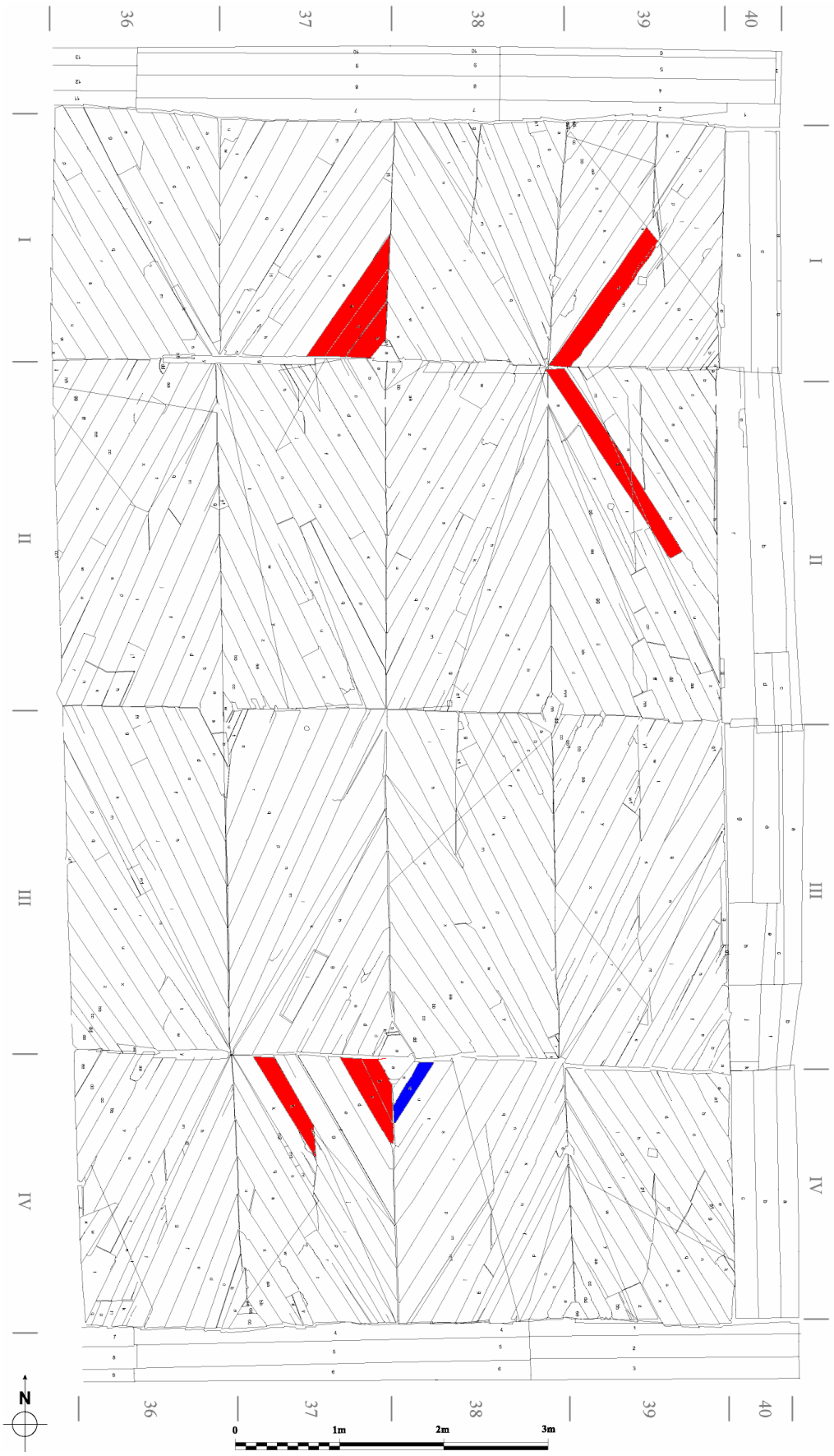

Figure 6 Bay 1 board plan (as if seen from above) showing panels 36/I – 39/IV and the location of the analysed oak boards; • dated; • undated

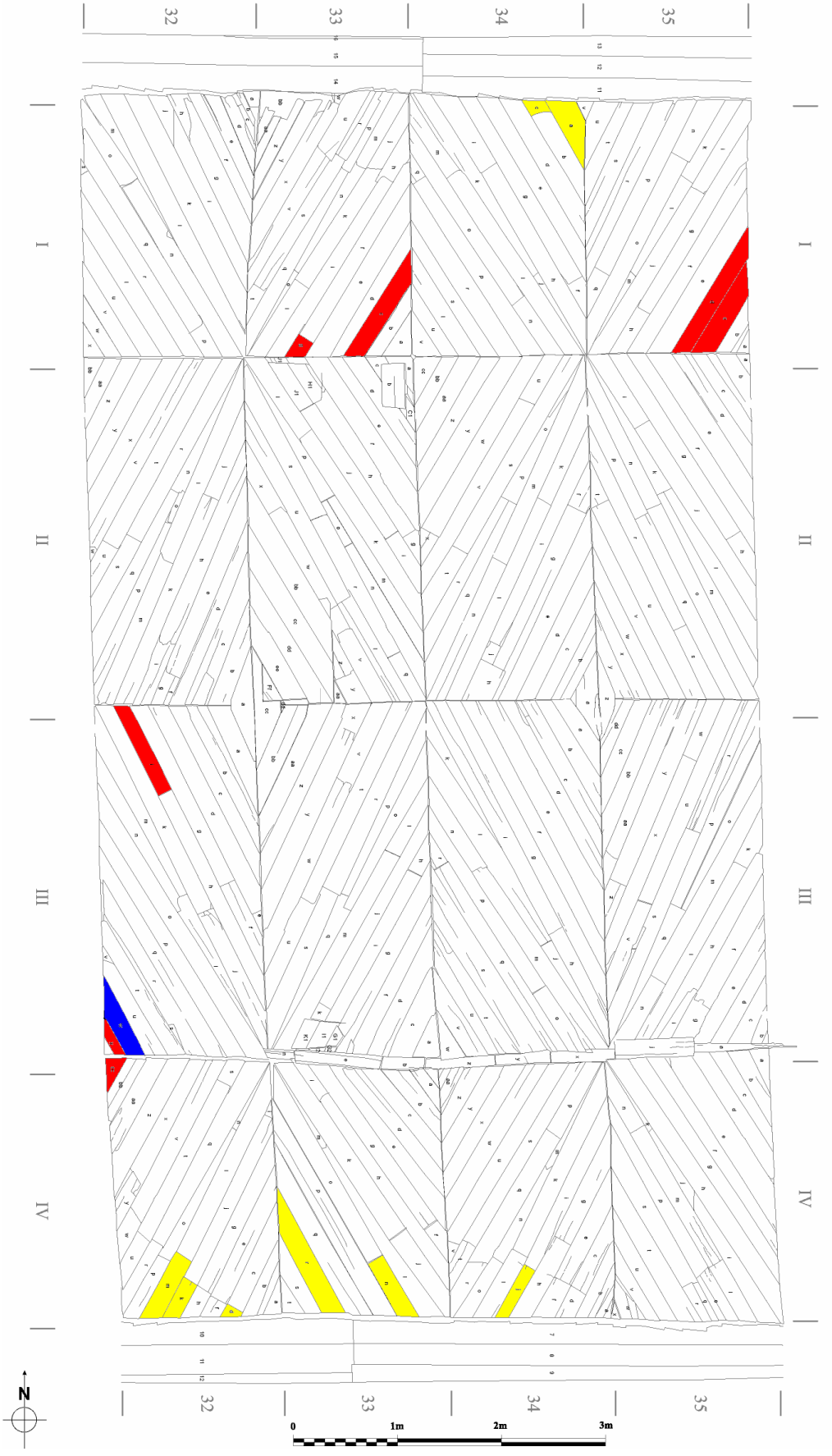

Figure 7 Bay 2 board plan (as if seen from above) showing panels 32/I – 35/IV and the location of the analysed boards; • oak dated; • oak undated; • conifer identification

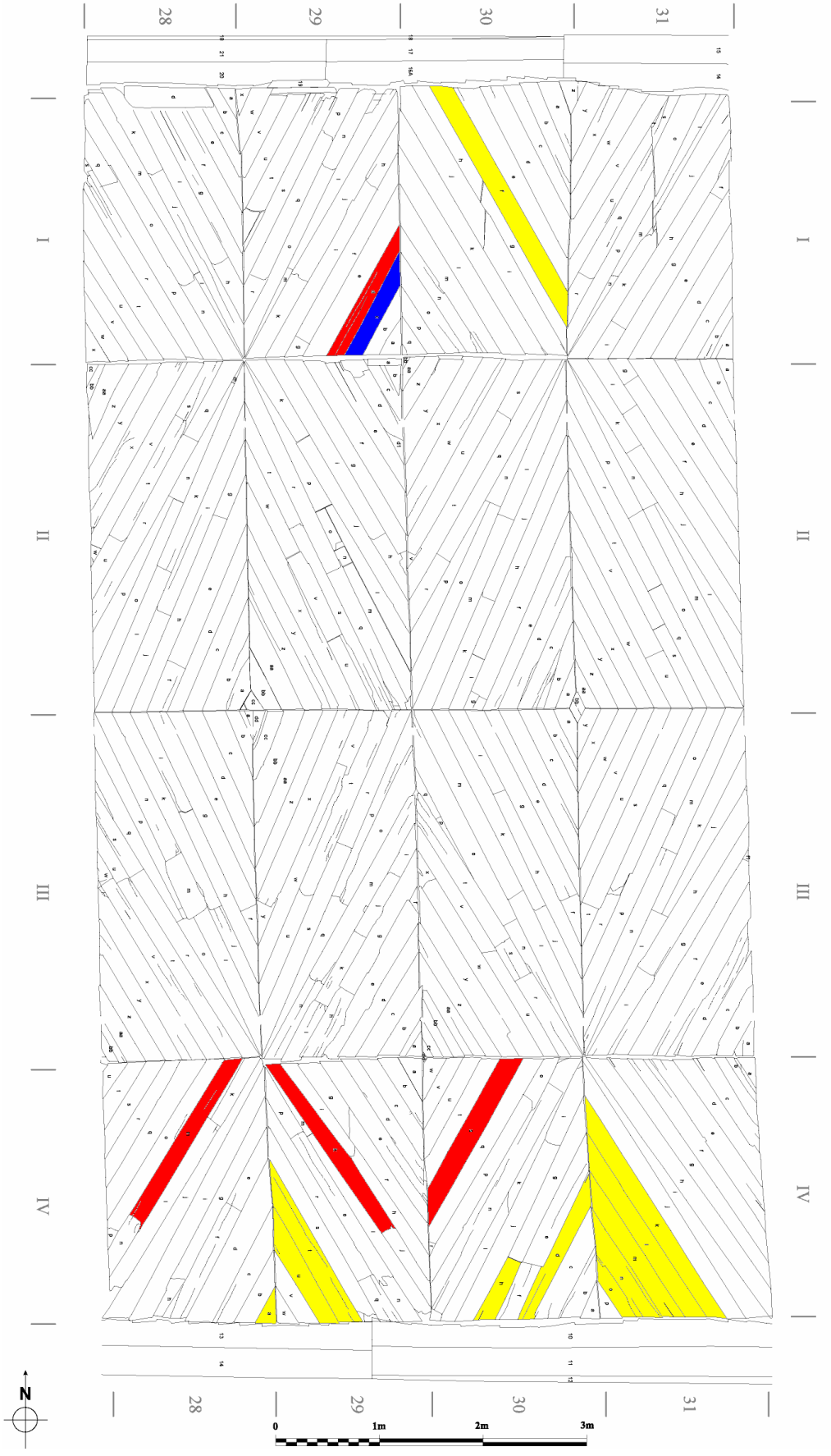

Figure 8 Bay 3 board plan (as if seen from above) showing panels 28/I – 31/IV and the location of the analysed boards; • oak dated; • oak undated; • conifer identification

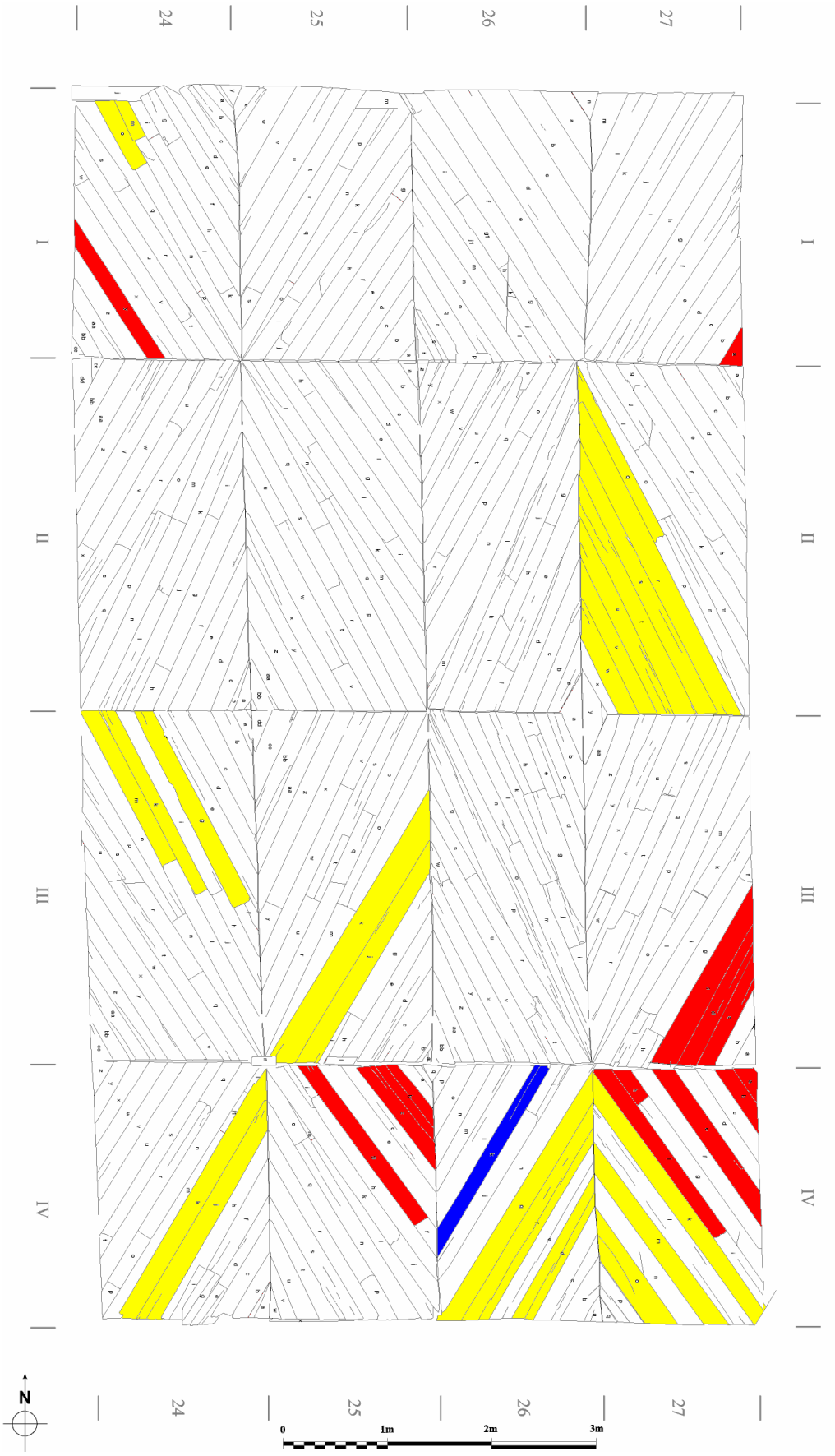

Figure 9 Bay 4 board plan (as if seen from above) showing panels 24/I – 27/IV and the location of the analysed boards; • oak dated; • oak undated; • conifer identification

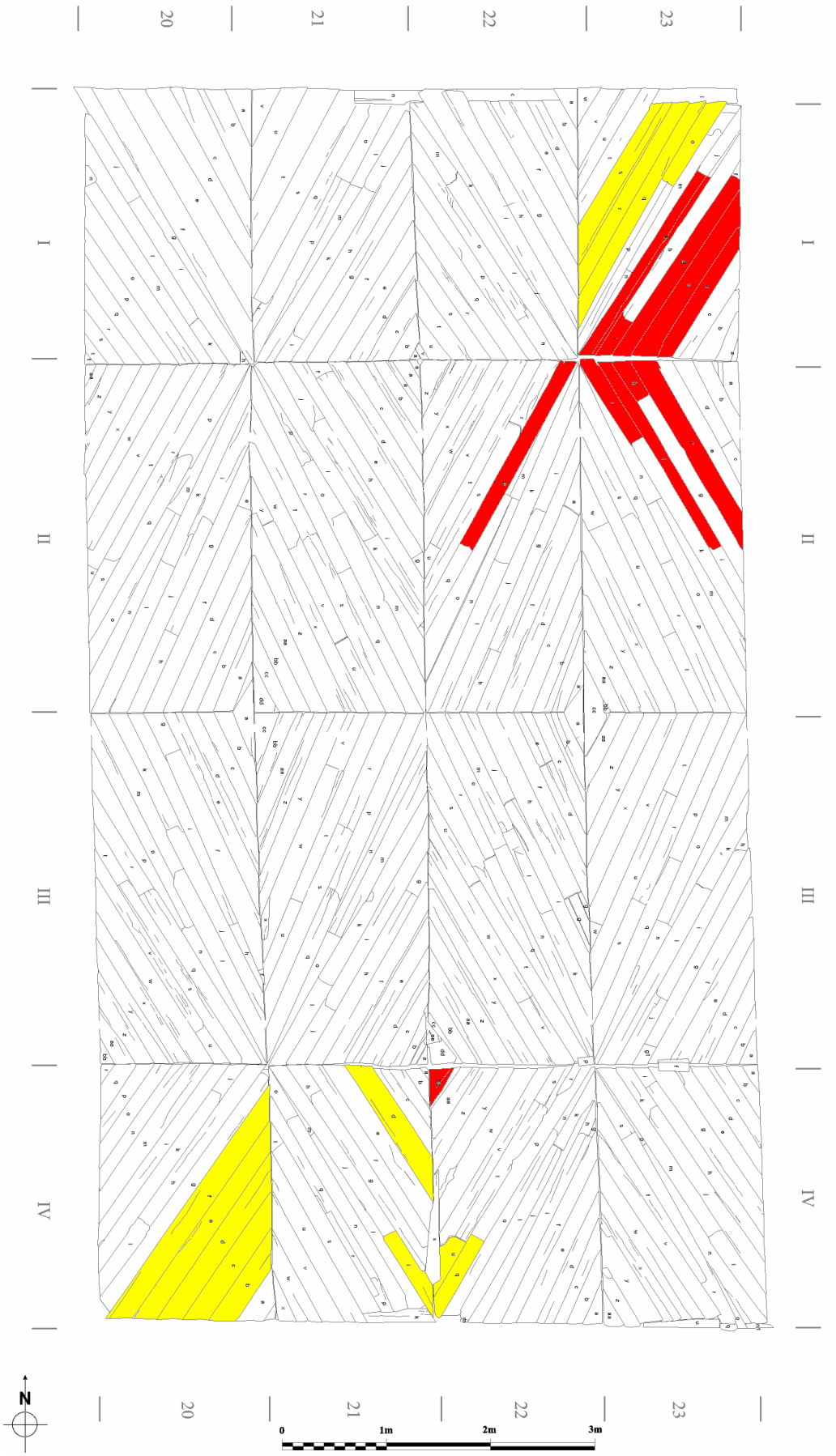

Figure 10 Bay 5 board plan (as if seen from above) showing panels 20/I – 23/IV and the location of the analysed boards; • oak dated; • oak undated; • conifer identification

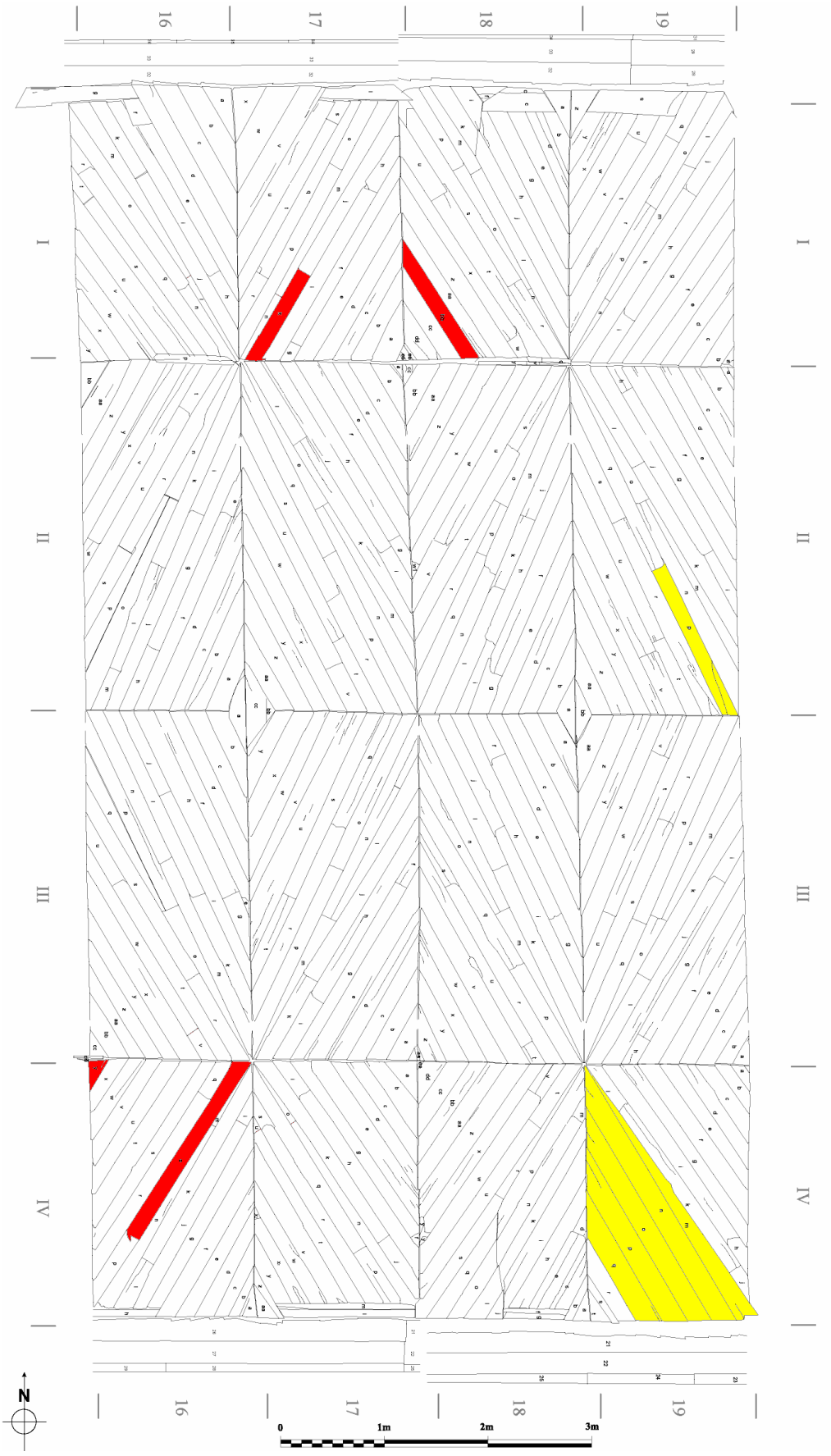

Figure 11 Bay 6 board plan (as if seen from above) showing panels 16/I – 19/IV and the location of the analysed boards; • oak dated; • oak undated; • conifer identification

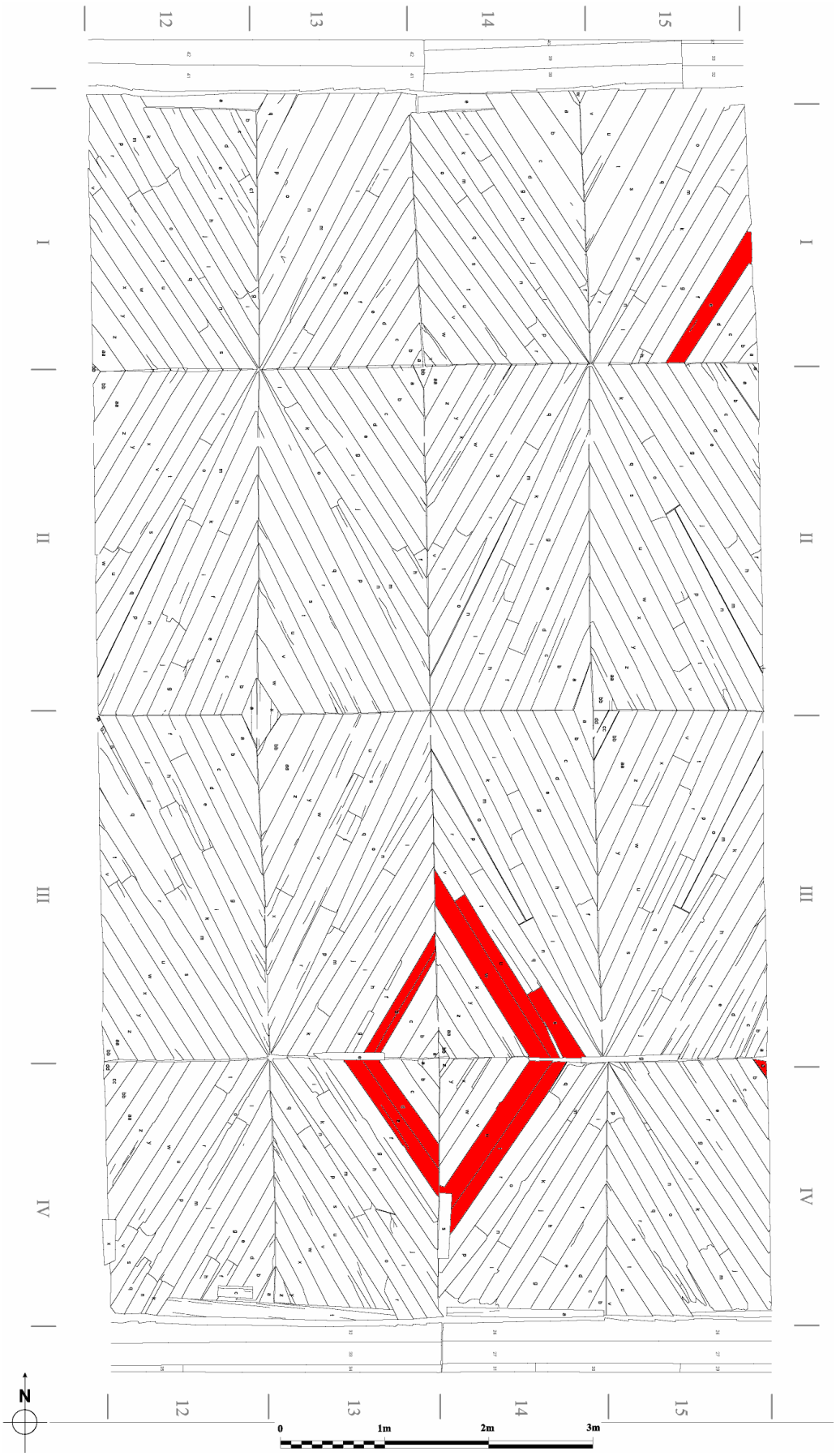

Figure 12 Bay 7 board plan (as if seen from above) showing panels 12/I – 15/IV and the location of the analysed oak boards; • dated; • undated

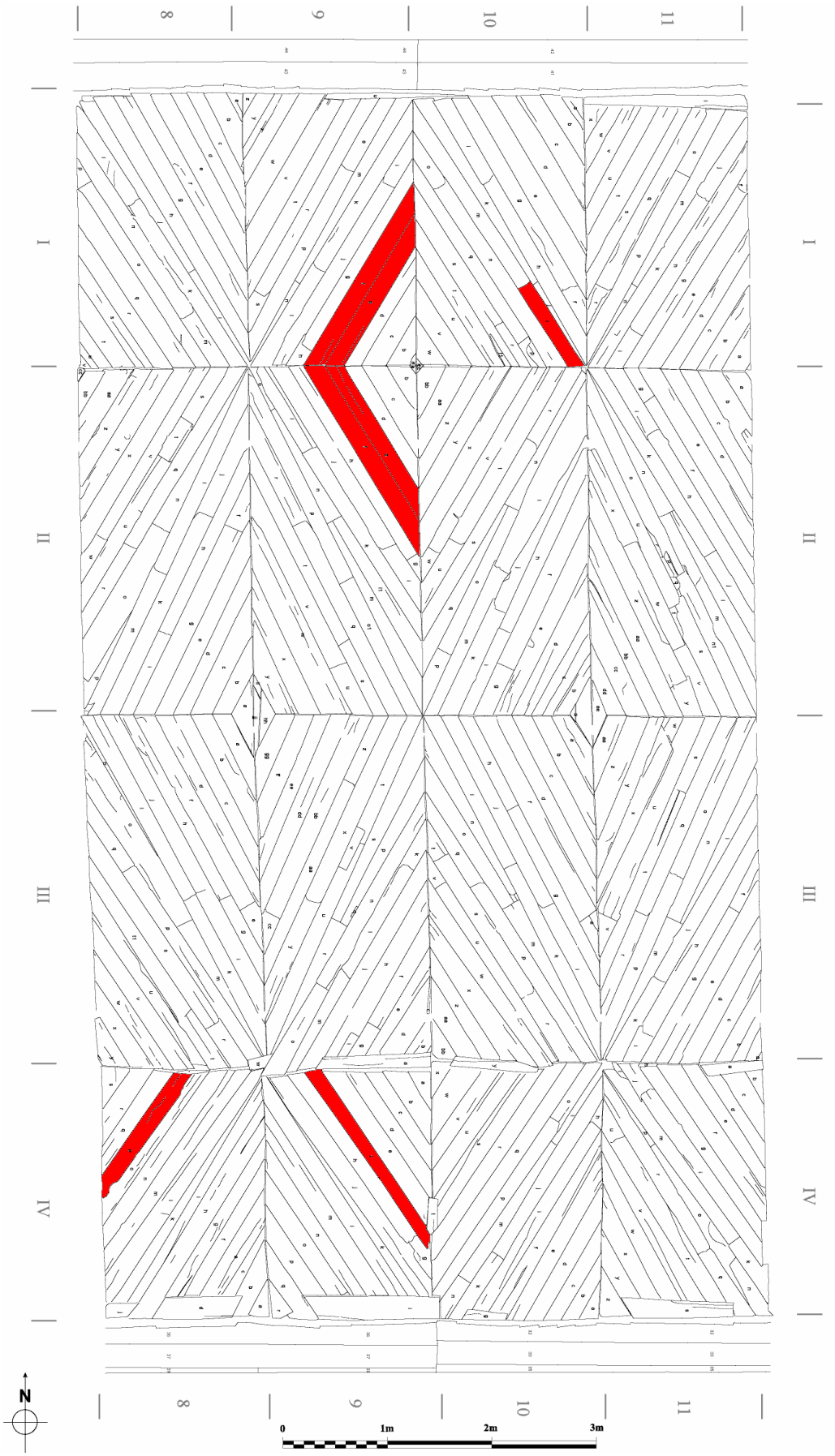

Figure 13 Bay 8 board plan (as if seen from above) showing panels 8/I – 11/IV and the location of the analysed oak boards; • dated; • undated

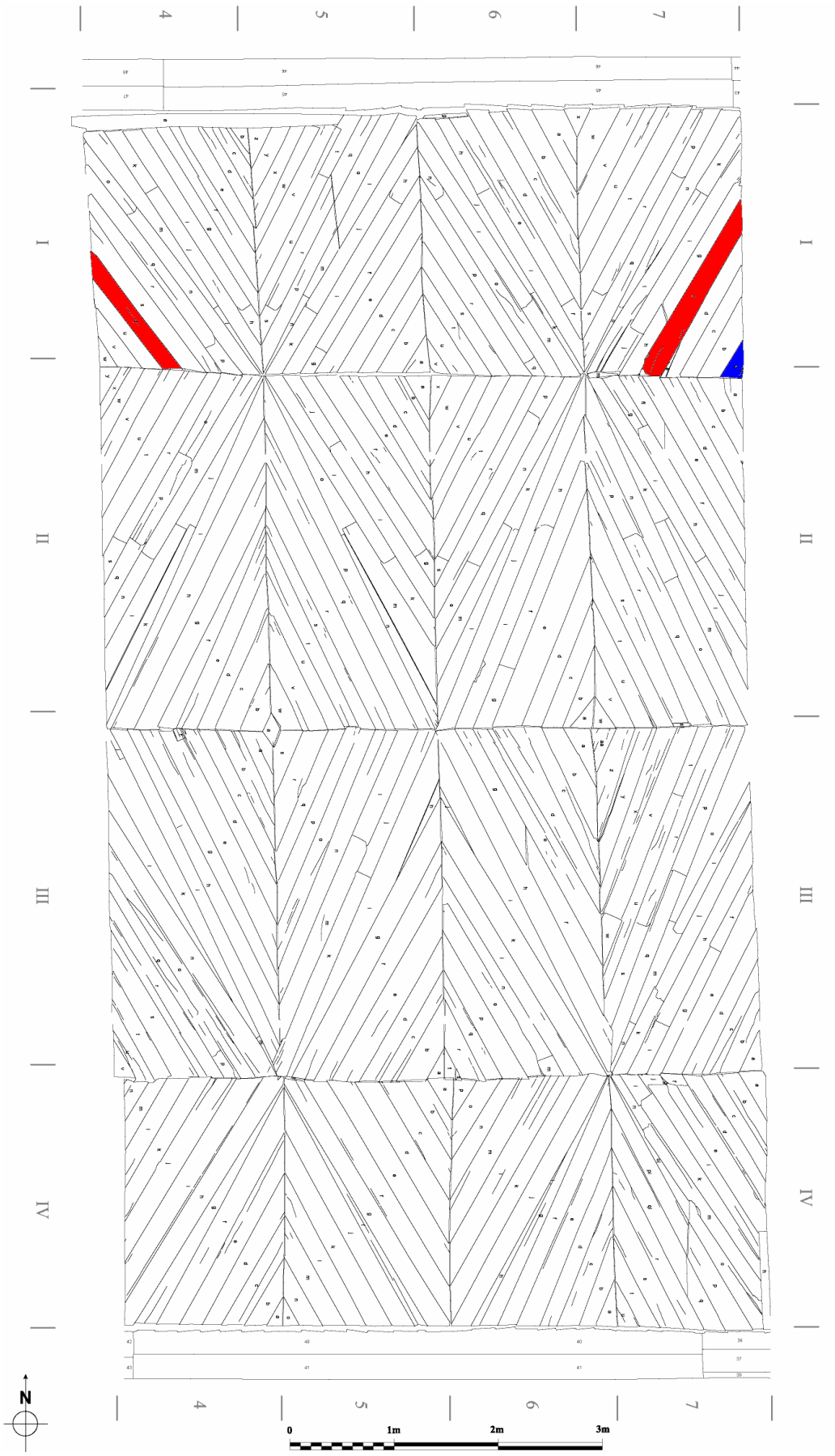

Figure 14 Bay 9 board plan (as if seen from above) showing panels 4/I – 7/IV and the location of the analysed oak boards; • dated; • undated

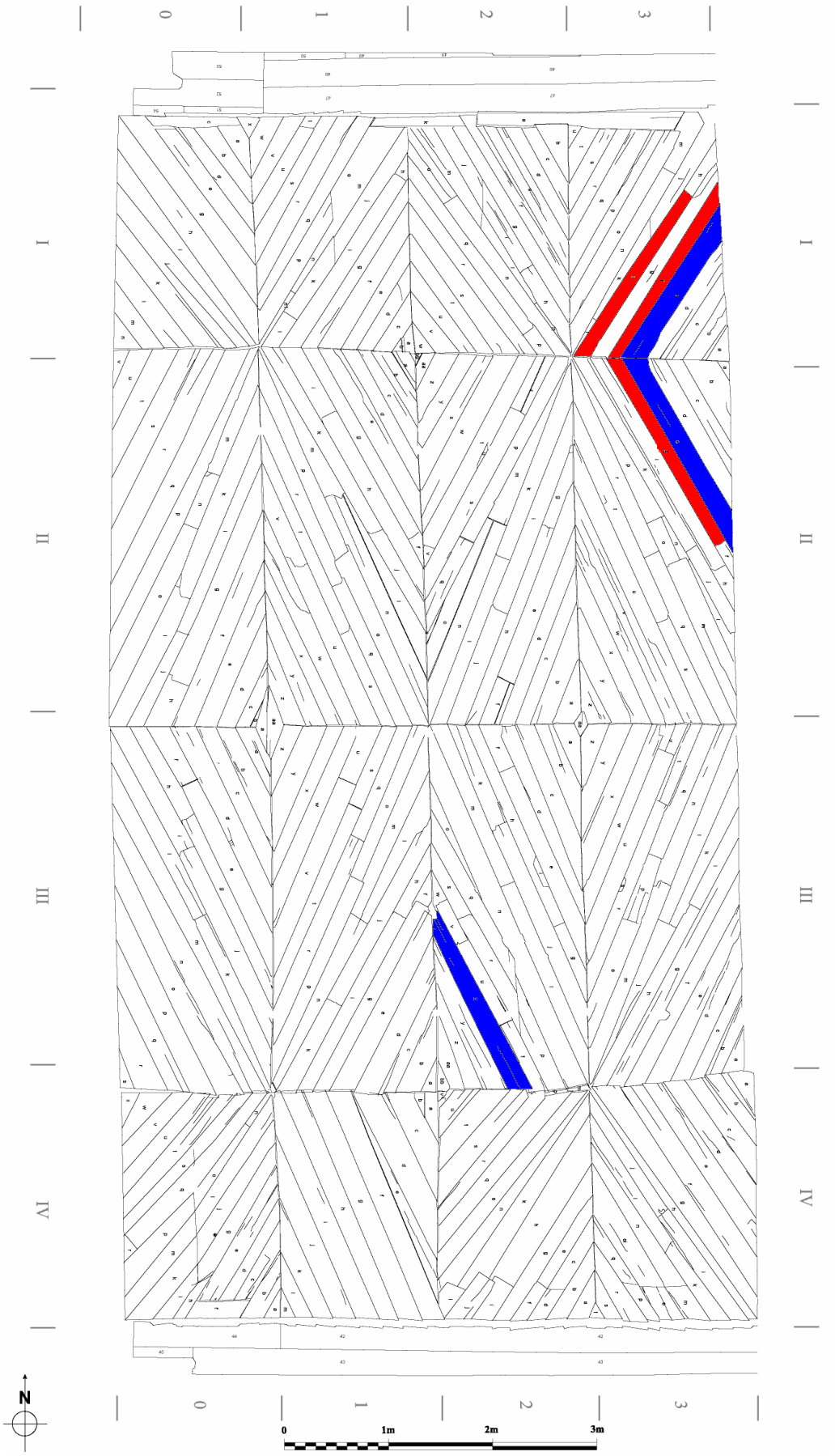

Figure 15 Bay 10 board plan (as if seen from above) showing panels 0/I – 3/IV and the location of the analysed oak boards; • dated; • undated

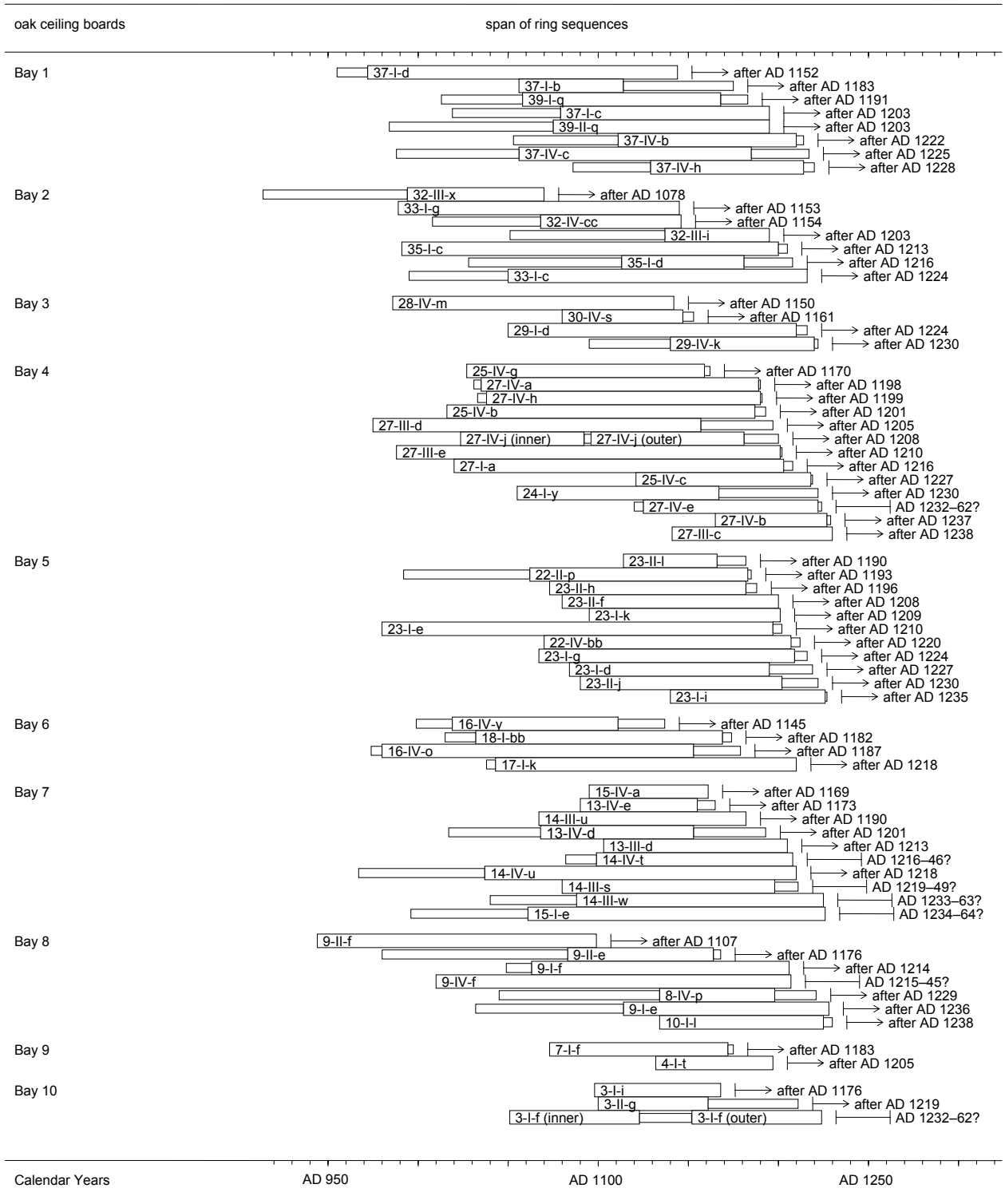

Figure 16 Bar diagram showing the chronological positions of the dated series from the nave ceiling boards at Peterborough Cathedral. The estimated earliest felling date or possible felling period is also shown for each series. Wide bars are measured heartwood rings, narrow bars are estimated numbers of unmeasured heartwood rings

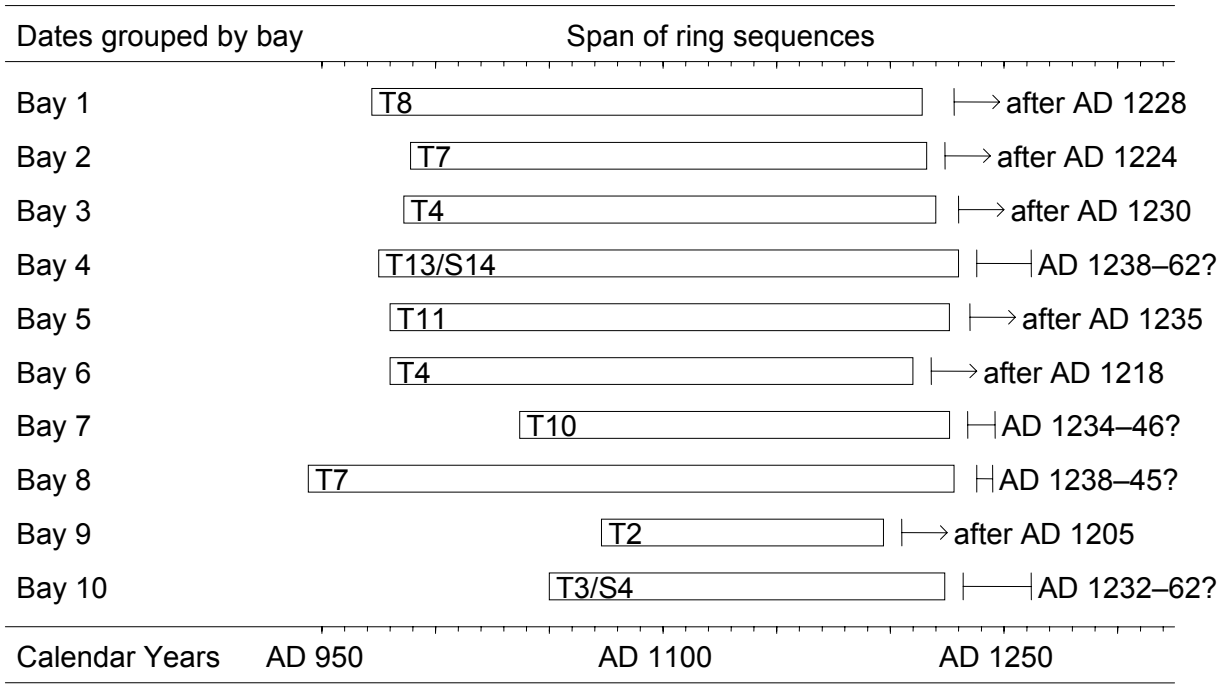

Figure 17 Diagram showing the chronological positions of the individual bay chronologies with their associated combined felling date interpretations

Table 1 List of sequences obtained from the nave ceiling boards at Peterborough Cathedral, see Figures 5-14 for details of board locations. The data from each individual board sequence is listed in Appendix 1

KEY
Board – panel identification number and board identification letter according to The Perry Lithgow Partnership and Hugh Harrison (2003)
Number of rings - total number of measured
nn+ or +*nn* – number of unmeasured rings
+?hs – possible heartwood/sapwood boundary present
ARW - average ring width in millimetres
Board width - maximum width in millimetres
Where the ring sequences from sections of a single board could not be linked the details are given for each section
Last two columns provide a concordance for board series number and the imprint numbers

Bay 1

Board	part	Total number of rings	ARW	Board Width (mm)	Date of measured ring sequence	Series	Imprints
39-I-q		*45*+111+*15*	1.13	200	AD 1058–1168	3	9–12, 34–5
39-II-q		*91*+121	0.93	205	AD 1075–1195	9	44–5
38-IV-w		*29*+67+*55*	1.19	175	undated	4	13–4
37-I-b		59+*61*	1.57	230	AD 1056–1114	1	1–3
37-I-c	inner	50+*10*	1.18	210	undated	2	4–8, 30–3, 42–3
	outer	117	1.06		AD 1079–1195		
37-I-d		*17*+173	1.18	225	AD 972–1144	8	25–9
37-IV-b		*58*+100+*4*	1.04	170	AD 1111–1210	5	15–6, 23, 36–7, 41
37-IV-c		*68*+130+*32*	1.11	215	AD 1056–1185	6	17–20, 24, 38–40
37-IV-h		*43*+86+*6*	1.76	235	AD 1129–1214	7	21–2

Bay 2

Board	part	Total number of rings	ARW	Board Width (mm)	Date of measured ring sequence	Series	Imprints
35-I-c		210+*5*	1.17	210	AD 991–1200	11	58–64
35-I-d	inner	*25*+56	0.83	175	undated	10	50–7
	outer	69+*27*	1.06		AD 1113–81		
33-I-c	inner	112	0.96	210	undated	12	65–9
	outer	167	0.88		AD 1050–1216		
33-I-g		157	1.20	195	AD 989–1145	13	70–3
32-III-i	inner	67	0.89	190	undated	16	78–80
	outer	59	0.98		AD 1137–95		
32-III-w		134+*3*	1.95	260	undated	22	94–6
32-III-x	inner	74	1.62	195	undated	21	91–3
	outer	77	1.02		AD 994–1070		
32-IV-cc	inner	90	1.16	200	undated	20	89–90
	outer	79	1.01		AD 1068–1146		

Bay 3

Board	part	Total number of rings	ARW	Board Width (mm)	Date of measured ring sequence	Series	Imprints
30-IV-s		68+*6*	1.42	230	AD 1080–1147	19	87–8
29-I-c		*81*+127	1.05	220	undated	14	46–9
29-I-d		161+*6*	1.01	190	AD 1050–1210	15	74–7
29-IV-k		*45*+81+*2*	1.68	210	AD 1140–1220	18	85–6
28-IV-m		157	1.02	170	AD 986–1142	17	81–4

Bay 4

Board	part	Total number of rings	ARW	Board Width (mm)	Date of measured ring sequence	Series	Imprints
27-I-a		184+*5*	1.14	230	AD 1020–1203	32	126–9
27-III-c		90	1.95	190	AD 1141–1230	45	168–71
27-III-d		183+*40*	0.80	190	AD 975–1157	46	172–6
27-III-e		214+*1*	0.99	235	AD 988–1201	47	177–82
27-IV-a		*4*+155+*1*	1.27	210	AD 1035–1189	23	97–100
27-IV-b		63+*2*	2.64	175	AD 1165–1227	24	101–2
27-IV-e		*5*+98+*2*+?hs	1.26	210	AD 1125–1222	25	103–4
27-IV-h		*5*+153+*1*	0.83	190	AD 1038–1190	26	105–7
27-IV-j	inner	70	1.04	200	AD 1023–92	44	164–7
	outer	86+*19*	1.04		AD 1096–1181		
26-IV-k		103+*20*	1.23	185	undated	48	183–5
25-IV-b		172+6	0.92	225	AD 1016–1187	27	108–11
25-IV-c		98+*1*	1.30	185	AD 1121–1218	28	112–4
25-IV-g		133+*3*	1.37	200	AD 1027–1159	29	115–8
24-I-y		113+*55*	1.06	185	AD 1055–1167	33	130–2

Bay 5

Board	part	Total number of rings	ARW	Board Width (mm)	Date of measured ring sequence	Series	Imprints
23-I-d		112+*24*	1.06	130	AD 1084–1195	43	161–3
23-I-e		218+*5*	0.91	235	AD 980–1197	37	141–4
23-I-g		143+*7*	1.21	195	AD 1067–1209	36	138–40
23-I-i		87+*1*	1.93	200	AD 1140–1226	35	136–7
23-I-k		107	1.61	215	AD 1095–1201	34	133–5
23-II-f		121	1.52	245	AD 1080–1200	38	145–7
23-II-h		110+*6*	1.64	185	AD 1073–1182	39	148–50
23-II-j		113+*20*	1.50	205	AD 1090–1202	40	151–4
23-II-l		53+*16*	1.85	130	AD 1114–66	41	155
22-II-p	inner	69	0.85	195	undated	42	156–60
	outer	122+*2*	0.92		AD 1062–1183		
22-IV-bb		138+*5*	1.21	295	AD 1070–1207	30	119–22

Bay 6

Board	part	Total number of rings	ARW	Board Width (mm)	Date of measured ring sequence	Series	Imprints
18-I-bb		*17*+138+*5*	0.90	190	AD 1032–1169	31	123–5
17-I-k		*5*+168	0.92	165	AD 1043–1210	65	238–41
16-IV-o		*6*+174+*26*	0.87	190	AD 980–1153	49	186–90
16-IV-y		*20*+93+*26*	1.37	195	AD 1019–1111	50	191–3

Bay 7

Board	part	Total number of rings	ARW	Board Width (mm)	Date of measured ring sequence	Series	Imprints
15-I-e		*65*+166+?hs	0.74	185	AD 1061–1226	64	234–7
15-IV-a		67	1.65	130	AD 1095–1161	51	194–5
14-III-s		119+*13*+?hs	1.56	220	AD 1080–1198	54	203–6
14-III-u		116	0.95	105	AD 1067–1182	55	207–8
14-III-w		*48*+138+?hs	1.15	220	AD 1088–1225	56	209–12
14-IV-t		*17*+110+?hs	1.15	155	AD 1099–1208	52	196–8
14-IV-u		*70*+174	0.93	230	AD 1037–1210	53	199–202
13-III-d		*103*	1.36	160	AD 1103–1205	68	247–8
13-IV-d		*51+86+40*	0.86	200	AD 1068–1153	66	242–4
13-IV-e		*66+10*	1.95	150	AD 1090–1155	67	245–6

Bay 8

Board	part	Total number of rings	ARW	Board Width (mm)	Date of measured ring sequence	Series	Imprints
10-I-l		92+*5*	1.99	195	AD 1134–1225	63	230–3
9-I-e		*82*+115	0.91	185	AD 1114–1228	60	222–3
9-I-f		*14*+144	1.39	220	AD 1063–1206	59	218–21
9-II-e		*103*+82+*4*	1.21	225	AD 1083–1164	62	228–9
9-II-f		156	1.41	225	AD 944–1099	61	224–7
9-IV-f		198+?hs	0.86	180	AD 1010–1207	57	213–5
8-IV-p		*89*+65+*23*	1.07	170	AD 1134–98	58	216–7

Bay 9

Board	part	Total number of rings	ARW	Board Width (mm)	Date of measured ring sequence	Series	Imprints
7-I-a		144+*40*	0.75	215	undated	69	249–53
7-I-f		100+*3*	1.98	215	AD 1073–1172	70	254–8
4-I-t		66	2.83	160	AD 1132–97	75	281–2, 286–9

Bay 10

Board	part	Total number of rings	ARW	Board Width (mm)	Date of measured ring sequence	Series	Imprints
3-I-e	inner	64+*6*	1.60	245	undated	71	259–66
	outer	55+*15*	1.33		undated		
3-I-f	inner	76+*26*	1.00	175	AD 1050-1125	72	267–71
	outer	73+?hs	1.00		AD 1152–1224		
3-I-i		71	1.27	170	AD 1098–1168	76	283–5
3-II-e		102+*93*	0.81	230	undated	73	271–6
3-II-g		62+*50*	1.29	150	AD 1100–61	74	277–80
2-III-x		~70	~1.50	250	unmeasurable	77	290–1

Table 2 *t*-value matrix between the timbers forming the interim Peterborough Cathedral Nave Bay 1 board chronology PCNBB1. KEY - = *t*-value less than 3.0, \ = overlap less than 15 years

Bay 1	39-II-q	37-I-b	37-I-c	37-I-d	37-IV-b	37-IV-c	37-IV-h
39-I-q	7.94	6.89	8.89	-	4.43	7.19	-
39-II-q		3.42	7.39	-	6.23	7.95	3.47
37-I-b			5.84	-	\	3.42	\
37-I-c				3.50	5.57	6.78	3.37
37-I-d					4.61	6.27	-
37-IV-b						6.17	4.78
37-IV-c							3.58

Table 3 *t*-value matrix between the timbers forming the interim Peterborough Cathedral Nave Bay 2 board chronology PCNBB2. KEY - = *t*-value less than 3.0, \ = overlap less than 15 years

Bay 2	35-I-d	33-I-c	33-I-g	32-III-i	32-III-x	32-IV-cc
35-I-c	6.00	3.19	-	-	3.50	4.18
35-I-d		7.14	4.18	-	\	4.50
33-I-c			-	-	3.32	5.94
33-I-g				\	3.34	4.33
32-III-i					\	\
32-III-x						\

Table 4 *t*-value matrix between the timbers forming the interim Peterborough Cathedral Nave Bay 3 board chronology PCNBB3. KEY - = *t*-value less than 3.0, \ = overlap less than 15 years

Bay 3	29-I-d	29-IV-k	28-IV-m
30-IV-s	3.89	\	-
29-I-d		4.97	4.15
29-IV-k			\

Table 5 *t*-value matrix between the timbers forming the interim Peterborough Cathedral Nave Bay 4 board chronology PCNBB4. KEY - = *t*-value less than 3.0, \ = overlap less than 15 years

Bay 4	27-III-c	27-III-d	27-III-e	27-IV-a	27-IV-b	27-IV-e	27-IV-h	27-IV-j	27-IV-j	25-IV-b	25-IV-c	25-IV-g	24-I-y
27-I-a	-	-	-	-	-	3.46	-	-	-	4.15	3.02	3.21	3.23
27-III-c		-	-	-	15.74	-	-	\	-	-	3.75	-	-
27-III-d			3.86	-	\	-	-	-	-	-	-	3.36	-
27-III-e				-	-	3.62	-	3.60	3.25	5.13	-	3.27	-
27-IV-a					-	3.71	4.71	-	5.56	6.14	4.68	-	-
27-IV-b						-	-	\	-	-	3.25	\	\
27-IV-e							-	\	4.05	-	4.74	-	-
27-IV-h								4.37	-	5.70	-	3.99	-
27-IV-j									\	4.45	\	4.13	-
27-IV-j										-	5.66	3.16	-
25-IV-b											-	4.77	-
25-IV-c												-	-
25-IV-g													3.26

Table 6 *t*-value matrix between the timbers forming the interim Peterborough Cathedral Nave Bay 5 board chronology PCNBB5. KEY - = *t*-value less than 3.0

Bay 5	23-I-e	23-I-g	23-I-i	23-I-k	23-II-f	23-II-h	23-II-j	23-II-l	22-II-p	22-IV-bb
23-I-d	3.73	3.63	3.98	3.13	3.83	3.07	3.75	5.12	4.59	-
23-I-e		4.85	3.05	3.51	3.47	4.20	4.82	3.52	4.20	-
23-I-g			4.93	6.87	7.31	5.35	5.92	-	5.82	7.08
23-I-i				3.00	4.83	3.21	5.92	-	-	4.88
23-I-k					3.86	4.68	4.47	3.30	5.08	3.00
23-II-f						5.63	3.73	4.89	5.41	6.79
23-II-h							4.39	-	4.02	4.60
23-II-j								-	5.80	4.54
23-II-l									4.77	3.42
22-II-p										5.32

Table 7 *t*-value matrix between the timbers forming the interim Peterborough Cathedral Nave Bay 6 board chronology PCNBB6. KEY - = *t*-value less than 3.0

Bay 6	17-I-k	16-IV-o	16-IV-y
18-I-bb	7.21	4.39	-
17-I-k		5.61	-
16-IV-o			4.73

Table 8 *t*-value matrix between the timbers forming the interim Peterborough Cathedral Nave Bay 7 board chronology PCNBB7. KEY - = *t*-value less than 3.0

Bay 7	15-IV-a	14-III-s	14-III-u	14-III-w	14-IV-t	14-IV-u	13-III-d	13-IV-d	13-IV-e
15-I-e	-	3.67	3.67	3.42	6.92	3.44	-	3.75	3.93
15-IV-a		5.89	-	4.57	-	3.26	3.72	-	3.34
14-III-s			3.86	3.43	5.37	4.30	7.16	3.58	3.54
14-III-u				-	3.59	3.86	-	-	-
14-III-w					3.14	3.04	-	-	4.21
14-IV-t						4.20	4.41	3.48	3.48
14-IV-u							3.58	-	5.23
13-III-d								-	-
13-IV-d									-

Table 9 *t*-value matrix between the timbers forming the interim Peterborough Cathedral Nave Bay 8 board chronology PCNBB8. KEY - = *t*-value less than 3.0, \ = overlap less than 15 years

Bay 8	9-I-e	9-I-f	9-II-e	9-II-f	9-IV-f	8-IV-p
10-I-l	4.25	-	-	\	-	3.72
9-I-e		3.99	-	\	3.42	-
9-I-f			3.51	3.01	3.17	4.08
9-II-e				-	-	-
9-II-f					-	\
9-IV-f						4.57

Table 10 *t*-value matrix between the timbers forming the interim Peterborough Cathedral Nave Bay 9 board chronology PCNBB9

Bay 9	4-I-t
7-I-f	4.44

Table 11 *t*-value matrix between the timbers forming the interim Peterborough Cathedral Nave Bay 10 board chronology PCNBB10. KEY - = *t*-value less than 3.0, \ = overlap less than 15 years

Bay 10	3-I-f *(o)*	3-I-i	3-II-g
3-I-f *(i)*	\	3.47	-
3-I-f *(o)*		-	\
3-I-i			-

Table 12 *t*-value matrix between the dated boards from Peterborough Cathedral Nave Bay 1, and the other 9 interim Bay chronologies. KEY - = *t*-value less than 3.0

Bay 1	Bay 2	Bay 3	Bay 4	Bay 5	Bay 6	Bay 7	Bay 8	Bay 9	Bay 10
39-I-q	6.74	6.34	7.90	7.76	6.87	7.10	4.92	5.29	4.13
39-II-q	9.64	9.11	9.55	8.96	9.40	8.84	7.21	7.10	6.00
37-I-b	3.66	3.19	4.82	4.13	3.13	3.75	-	-	-
37-I-c outer	8.39	7.48	8.83	8.77	7.07	7.43	4.96	6.52	6.23
37-I-d	8.65	8.23	7.77	7.20	6.18	4.67	7.49	5.26	3.35
37-IV-b	6.80	6.18	7.93	7.11	4.81	9.54	8.97	8.15	3.22
37-IV-c	10.55	9.72	9.23	8.76	7.35	8.48	9.02	6.16	4.30
37-IV-h	5.06	5.60	5.97	5.98	3.50	6.01	4.99	8.47	3.38

Table 13 *t*-value matrix between the dated boards from Peterborough Cathedral Nave Bay 2, and the other 9 interim Bay chronologies. KEY - = *t*-value less than 3.0, \ = overlap less than 15 years

Bay 2	Bay 1	Bay 3	Bay 4	Bay 5	Bay 6	Bay 7	Bay 8	Bay 9	Bay 10
35-I-c	11.95	11.03	11.20	9.35	9.39	9.12	7.78	5.88	5.77
35-I-d outer	8.56	7.62	5.91	7.63	5.86	6.79	6.03	6.44	3.52
33-I-c outer	6.34	4.47	3.57	5.39	4.07	4.36	3.83	6.66	-
33-I-g	4.74	4.18	3.20	3.14	4.35	-	5.55	4.14	-
32-III-i outer	4.30	4.79	3.40	3.13	3.03	4.33	-	4.67	-
32-III-x outer	-	3.43	-	3.62	3.75	-	-	\	-
32-IV-cc outer	6.93	6.24	5.30	4.64	4.63	4.36	6.83	7.02	-

Table 14 *t*-value matrix between the dated boards from Peterborough Cathedral Nave Bay 3, and the other 9 interim Bay chronologies. KEY - = *t*-value less than 3.0

Bay 3	Bay 1	Bay 2	Bay 4	Bay 5	Bay 6	Bay 7	Bay 8	Bay 9	Bay 10
30-IV-s	4.38	3.92	5.48	5.41	5.37	3.52	4.25	-	3.39
29-I-d	11.87	10.59	12.38	10.43	11.60	9.62	11.75	8.10	6.32
29-IV-k	7.28	5.27	6.51	6.59	3.74	4.33	6.29	6.40	-
28-IV-m	6.49	6.89	8.04	6.31	4.10	-	6.24	-	-

Table 15 *t*-value matrix between the dated boards from Peterborough Cathedral Nave Bay 4, and the other 9 interim Bay chronologies. KEY - = *t*-value less than 3.0

Bay 4	Bay 1	Bay 2	Bay 3	Bay 5	Bay 6	Bay 7	Bay 8	Bay 9	Bay 10
27-I-a	6.57	6.94	4.97	4.70	4.69	4.82	4.42	6.03	3.62
27-III-c	4.45	-	5.23	5.45	-	4.91	4.51	3.20	3.19
27-III-d	4.41	-	5.78	4.41	-	-	-	-	-
27-III-e	7.35	7.30	7.81	9.19	7.56	3.97	5.21	3.22	4.94
27-IV-a	5.06	4.04	4.43	6.76	6.20	6.26	3.84	3.12	3.19
27-IV-b	5.52	-	4.60	5.01	-	6.27	5.03	3.53	3.72
27-IV-e	6.34	4.91	4.66	6.56	-	5.67	4.13	4.89	4.52
27-IV-h	3.84	4.06	4.50	3.82	5.07	3.90	3.84	-	-
27-IV-j inner	5.08	3.40	4.61	6.27	4.26	-	4.04	-	-
27-IV-j outer	5.18	4.49	7.08	8.08	4.98	4.42	6.28	-	5.59
25-IV-b	6.58	5.90	5.71	6.36	6.78	4.33	6.02	-	3.48
25-IV-c	6.72	3.84	5.61	5.76	4.39	7.11	5.68	5.29	6.19
25-IV-g	7.40	8.20	7.54	5.05	4.45	5.20	7.07	4.62	3.26
24-I-y	4.56	4.00	3.77	3.22	-	3.51	-	3.81	-

Table 16 *t*-value matrix between the dated boards from Peterborough Cathedral Nave Bay 5, and the other 9 interim Bay chronologies. KEY - = *t*-value less than 3.0

Bay 5	Bay 1	Bay 2	Bay 3	Bay 4	Bay 6	Bay 7	Bay 8	Bay 9	Bay 10
23-I-d	5.32	4.84	5.54	7.20	3.96	5.48	3.67	5.01	5.53
23-I-e	10.63	8.81	8.41	9.28	7.83	6.76	7.27	5.83	5.66
23-I-g	8.00	6.03	9.82	8.60	7.87	7.92	7.29	4.48	6.32
23-I-i	4.72	4.05	5.28	6.42	3.40	4.58	5.45	4.39	4.76
23-I-k	4.84	4.43	4.92	4.67	6.94	4.38	4.73	-	6.07
23-II-f	6.57	6.69	7.20	7.20	5.58	7.80	7.13	5.33	5.55
23-II-h	7.33	6.19	6.79	10.73	5.30	8.88	6.10	3.59	6.09
23-II-j	8.19	5.94	7.50	6.98	6.68	5.58	6.57	5.30	5.67
23-II-l	6.25	7.13	4.03	6.03	5.18	5.12	6.43	4.70	4.40
23-II-p outer	7.51	7.68	8.50	8.14	7.20	5.50	6.15	6.42	4.97
23-IV-bb	5.37	5.36	6.67	8.21	4.31	6.53	7.01	3.60	4.69

Table 17 *t*-value matrix between the dated boards from Peterborough Cathedral Nave Bay 6, and the other 9 interim Bay chronologies. KEY - = *t*-value less than 3.0

Bay 6	Bay 1	Bay 2	Bay 3	Bay 4	Bay 5	Bay 7	Bay 8	Bay 9	Bay 10
18-I-bb	5.29	4.86	4.50	4.97	6.08	3.91	4.38	-	3.95
17-I-k	8.66	8.89	8.38	7.89	8.49	5.35	7.54	5.01	5.20
16-IV-o	6.46	5.80	5.86	5.80	5.93	3.80	5.72	-	3.43
16-IV-y	5.92	5.74	3.80	4.21	3.99	-	3.30	3.83	-

Table 18 *t*-value matrix between the dated boards from Peterborough Cathedral Nave Bay 7, and the other 9 interim Bay chronologies. KEY - = *t*-value less than 3.0

Bay 7	Bay 1	Bay 2	Bay 3	Bay 4	Bay 5	Bay 6	Bay 8	Bay 9	Bay 10
15-I-e	6.15	5.09	4.05	5.53	4.61	5.54	4.77	4.93	3.60
15-IV-a	3.94	4.06	3.36	5.60	4.34	-	3.30	4.84	-
14-III-s	8.30	7.01	7.29	10.31	9.30	4.90	6.92	5.73	5.18
14-III-u	6.38	6.42	5.74	7.14	6.78	6.20	5.14	3.78	4.14
14-III-w	3.67	4.28	-	-	-	-	3.14	3.78	-
14-IV-t	8.47	6.33	4.67	7.23	6.45	4.28	7.42	7.03	4.14
14-IV-u	8.19	6.30	6.80	8.59	6.55	4.89	7.12	7.62	4.50
13-III-d	6.51	4.89	5.66	7.01	8.11	3.27	6.84	5.37	5.61
13-IV-d	6.44	3.70	3.66	4.76	5.35	6.14	-	4.06	-
13-IV-e	3.65	5.27	4.37	4.82	3.76	-	6.60	4.46	-

Table 19 *t*-value matrix between the dated boards from Peterborough Cathedral Nave Bay 8, and the other 9 interim Bay chronologies. KEY - = *t*-value less than 3.0

Bay 8	Bay 1	Bay 2	Bay 3	Bay 4	Bay 5	Bay 6	Bay 7	Bay 9	Bay 10
10-I-l	4.53	3.93	6.04	5.41	6.09	5.13	4.79	3.97	3.23
9-I-e	5.29	5.44	6.79	7.49	5.85	3.30	5.66	3.82	3.05
9-I-f	8.26	6.08	7.22	7.41	6.77	4.16	6.70	5.13	3.61
9-II-e	4.03	4.34	3.93	4.57	4.42	3.73	4.88	4.55	-
9-II-f	5.81	4.95	5.38	-	3.94	3.52	-	-	-
9-IV-f	5.30	5.38	4.72	5.32	5.71	4.63	5.49	5.79	4.67
8-IV-p	5.50	4.10	4.75	6.02	6.06	3.64	7.38	4.59	3.91

Table 20 *t*-value matrix between the dated boards from Peterborough Cathedral Nave Bay 9, and the other 9 interim Bay chronologies

Bay 9	Bay 1	Bay 2	Bay 3	Bay 4	Bay 5	Bay 6	Bay 7	Bay 8	Bay 10
7-I-f	9.25	7.56	5.49	6.31	4.97	4.03	8.63	7.31	4.10
4-I-t	8.73	7.11	7.14	6.10	7.51	3.98	7.10	5.60	4.24

Table 21 *t*-value matrix between the dated boards from Peterborough Cathedral Nave Bay 10, and the other 9 interim Bay chronologies. KEY - = *t*-value less than 3.0

Bay 10	Bay 1	Bay 2	Bay 3	Bay 4	Bay 5	Bay 6	Bay 7	Bay 8	Bay 9
3-I-f inner	5.22	3.06	3.18	4.07	4.07	3.42	-	-	-
3-I-f outer	3.55	-	-	5.48	4.54	3.15	-	-	3.44
3-I-i	4.52	4.81	5.55	4.56	5.06	5.71	5.45	5.36	3.75
3-II-g	5.31	5.07	5.58	4.74	6.27	4.64	3.99	4.26	5.37

Table 22 *t*-value matrix between the ten interim Bay Chronologies used to form the Peterborough Cathedral Nave Board chronology PCNB

	Bay 2	**Bay 3**	**Bay 4**	**Bay 5**	**Bay 6**	**Bay 7**	**Bay 8**	**Bay 9**	**Bay 10**
Bay 1	11.87	13.07	12.50	12.16	10.10	11.17	9.95	11.62	6.95
Bay 2		10.95	8.08	9.05	10.06	8.05	9.41	10.09	3.78
Bay 3			12.65	10.01	8.99	7.22	10.02	8.06	5.00
Bay 4				12.63	8.09	10.44	6.46	8.09	8.10
Bay 5					8.80	8.50	9.04	7.76	7.74
Bay 6						6.69	7.51	5.30	6.23
Bay 7							7.80	10.37	5.10
Bay 8								8.08	5.10
Bay 9									5.88

Table 23 Dating the Peterborough Cathedral Nave Board chronology PCNB. Example *t*-values with independent reference chronologies

Reference Chronology	**PCNB**
	AD 944–1230
Denmark West (Bonde pers comm)	6.25
English (import) Hull coffins (Tyers 1998)	6.06
English (import) London PWB88 (Tyers 1993)	8.39
Germany Lüneburg (Leuschner pers comm)	8.70
Germany Niedersachsen Nord (Leuschner pers comm)	8.97
Germany Schleswig-Holstein (Eckstein *et al* 1970)	9.08
Germany Trier region (Hollstein 1980)	6.17
Germany Weserbergland (Delorme 1972)	8.13
Netherlands Groningen Wolters Noordhof (Jansma 1995)	6.48
Poland East Pomerania (Wazny 1990)	5.13

Table 24: Details of the conifer boards from the nave ceiling, Peterborough Cathedral, sampled for wood type identification, see Figures 6–10 for board locations

KEY
Board – panel identification number and board identification letter
ARW – estimated average growth rate in millimetres per year
Wood type – type A is the *Pinus sylvestris* group; type B is the *Picea/Larix* group which is highly likely to be *Picea abies*. See text for further details.
Expected Date is based on The Perry Lithgow Partnership database annotations
Frieze indicates boards with a frieze underpaint layer

Bay 2

Board	ARW	Wood type	Expected Date
34-I-a	>4	B	1830
34-I-c	>4	B	1830
34-IV-j	2–4	B	1830
33-IV-n	2–4	B	1830
33-IV-r	<2	A	1830
32-IV-d	<2	A	1830
32-IV-k	<2	A	1830
32-IV-m	<2	A	1830

Bay 3

Board	ARW	Wood type	Expected Date
31-IV-k	2–4	A	1830
31-IV-l	<2	A	1830
31-IV-m	<2	A	1830
31-IV-n	<2	A	1830
31-IV-o	>4	A	1830
30-I-f	2–4	A	1740
30-IV-d	<2	A	1830
30-IV-h	2–4	A	1830
29-IV-t	<2	A	1830
29-IV-u	>4	A	1830
28-IV-a	>4	A	1830

Bay 4

Board	ARW	Wood type	Expected Date
27-II-q	<2	A	1740 frieze
27-II-r	<2	A	1740 frieze
27-II-s	<2	A	1740 frieze
27-II-t	<2	A	1740 frieze
27-II-u	<2	A	1740 frieze
27-II-v	<2	A	1740 frieze
27-II-w	2-4	A	1740 frieze
27-IV-k	<2	A	1830
27-IV-m	knot	cf A	1830
27-IV-o	<2	B	1830
26-IV-d	<2	B	1830
26-IV-f	<2	B	1830
26-IV-g	<2	A	1830
25-III-g	<2	A	1830
25-III-j	<2	B	1830
25-III-k	2–4	B	1830
24-III-k	<2	A	1830
24-III-m	<2	A	1830
24-I-m	<2	A	1740
24-I-o	2–4	A	1740
24-IV-j	<2	A	1740
24-IV-k	<2	A	1740

Bay 5

Board	ARW	Wood type	Expected Date
23-I-o	<2	A	1740
23-I-q	<2	A	1740
23-I-r	<2	A	1740
23-I-s	<2	A	1740
22-IV-q	2–4	A	1740
22-IV-u	<2	A	1740
21-IV-d	<2	A	1740
21-IV-i	<2	A	1740 frieze
20-I-b	2–4	B	1830
20-I-c	2–4	B	1830
20-I-d	2–4	B	1830
20-I-e	2–4	B	1830
20-I-f	>4	B	1830

Bay 6

Board	ARW	Wood type	Expected Date
19-II-p	>4	B	1830
19-IV-m	2–4	B	1830
19-IV-n	<2	B	1830
19-IV-o	<2	B	1830
19-IV-p	<2	B	1830
19-IV-q	<2	B	1830

Backing spars

Board	ARW	Wood type
Row 22 south beam	<2	A
Row 24 north beam	2–4	A
Row 26 north beam	<2	A
Row 26 south beam	<2	A

Appendix 1 Ring width data for each oak board analysed from Peterborough Cathedral Nave ceiling boards, 100 = 1mm

Board01

254	240	171	154	186	189	97	85	107	158
128	154	135	152	92	122	124	167	169	124
142	132	138	164	171	133	217	151	183	163
174	197	173	200	195	160	195	163	163	201
182	168	103	112	203	138	150	208	178	227
129	94	98	141	95	152	126	173	171	

Board02 inner

152	115	136	91	73	88	142	160	127	137
145	145	105	139	106	163	106	125	132	147
125	92	60	82	100	82	105	111	86	86
125	110	133	114	157	157	136	121	122	126
103	77	87	105	108	122	143	139	106	155

Board02 outer

94	103	102	116	119	110	111	110	166	133
151	143	122	141	128	116	132	151	139	89
71	141	94	104	116	113	105	97	80	115
109	99	98	103	97	96	92	102	70	135
109	130	123	124	138	96	76	64	81	75
62	76	83	76	86	88	88	80	80	92
88	126	148	113	94	109	130	115	111	105
103	72	87	78	128	97	103	98	106	94
86	131	121	97	104	116	94	77	79	115
94	112	115	155	147	119	105	117	87	106
95	87	99	94	132	130	95	114	110	99
99	108	119	100	94	91	97			

Board03

106	113	117	104	75	57	71	113	118	128
116	92	77	122	140	120	161	137	149	121
90	115	139	109	127	117	125	121	147	133
119	145	135	125	125	123	146	127	170	148
55	58	124	90	92	96	130	139	93	60
83	118	94	85	93	133	90	130	103	73
145	88	153	98	169	153	103	78	103	120
117	62	102	96	85	90	120	110	68	96
94	63	143	109	121	134	138	152	108	116
142	126	69	116	110	141	116	129	99	121
88	80	156	123	119	147	115	110	106	111
157									

Board04

106	121	114	88	107	118	143	144	143	128
100	81	92	117	110	111	151	137	120	101
92	102	82	105	101	137	94	128	110	112
75	117	119	126	107	141	124	118	99	104
152	133	100	113	113	136	138	141	132	129
147	156	127	105	139	121	121	115	126	130
147	124	130	131	101	106	131			

Board05

119	74	112	120	82	80	82	149	109	100
92	147	142	95	77	80	107	126	73	121
88	98	96	136	104	123	84	101	75	161
162	138	130	112	123	120	140	97	118	88
100	108	150	93	116	139	118	88	99	120
100	117	110	101	90	115	85	145	107	99
171	144	166	139	91	113	80	107	98	84
97	99	97	99	99	121	128	92	84	104
84	98	91	74	101	69	67	74	63	67
86	81	112	94	79	83	59	66	68	83

Board06

215	184	142	144	148	75	88	83	75	149
118	130	148	120	78	61	104	92	100	41
159	102	93	138	133	138	146	122	160	162
203	113	138	149	141	149	207	114	104	103
151	98	54	53	116	96	90	129	145	96
125	52	60	74	112	78	121	75	132	133
105	59	123	86	116	55	148	142	74	45
93	76	113	47	98	116	132	66	173	120
109	147	159	73	155	160	140	132	96	165
114	171	58	124	66	81	107	144	118	105
161	125	109	65	207	136	129	99	122	53
59	60	109	56	91	121	105	109	75	59
81	74	71	90	103	94	99	144	101	92

Board07

101	126	134	140	121	167	129	160	146	200
149	211	246	150	235	330	243	219	275	157
249	148	161	153	226	238	208	224	241	127
159	181	210	279	244	187	178	156	101	157
140	123	232	175	239	124	126	193	121	172
149	160	95	169	270	214	221	179	160	171
155	256	249	197	168	114	207	245	122	194
171	139	152	153	214	164	149	128	124	135
120	116	130	154	143	150				

Board08

116	119	109	134	161	100	91	122	111	125
148	102	146	160	162	151	104	81	73	158
69	126	102	96	163	117	133	146	129	178
211	203	159	163	129	169	116	101	124	140
118	148	139	160	179	172	107	113	127	107
146	124	122	115	130	124	143	127	150	114
103	108	103	117	111	182	186	124	126	111
91	76	73	77	102	99	122	97	128	99
141	113	92	130	164	151	121	104	115	87
101	123	129	135	118	99	115	97	78	98
142	144	131	76	141	118	147	114	124	128
144	113	130	113	132	120	93	113	107	100
120	126	93	97	89	93	94	85	95	104
68	92	93	123	92	96	88	68	98	124
112	114	110	112	106	79	131	101	104	96
132	137	115	80	118	139	140	71	107	114
133	108	145	120	118	92	86	90	87	121
113	116	99							

Board09

129	88	104	114	126	109	87	119	128	128
99	131	125	134	131	113	100	96	120	95
107	112	127	76	63	95	84	82	105	141
78	104	57	77	100	91	93	97	121	102
148	76	83	113	98	125	84	159	167	88
76	65	64	92	61	93	80	74	64	78
70	78	89	94	51	102	78	97	98	77
109	116	95	77	80	60	82	61	93	86
95	77	109	67	64	80	85	71	103	93
83	78	52	81	69	72	94	111	118	103
61	77	52	61	83	73	79	67	121	82
95	126	142	84	67	87	84	74	67	88
119									

Board10 inner

34	62	58	61	50	60	54	96	119	110
73	68	61	75	38	25	40	68	63	40
51	60	69	69	80	54	104	95	75	103
94	129	111	156	132	118	136	137	124	122
76	87	119	132	106	123	102	83	66	62
55	56	64	79	69	85				

Board10 outer

92	67	65	49	50	65	55	72	60	104
122	64	55	51	65	56	53	97	100	98
62	78	76	92	123	118	98	181	168	117
184	201	252	182	239	186	150	126	99	91
176	202	179	177	140	93	63	117	100	100
91	83	70	64	59	82	83	82	81	124
135	92	76	126	77	107	99	87	111	

Board11

111	120	112	125	132	129	109	134	123	93
130	141	145	151	133	126	135	151	81	93
137	144	153	89	112	117	117	87	98	107
93	108	125	112	111	99	73	91	83	137
120	100	126	110	106	113	156	130	91	109
115	107	92	72	70	68	67	103	93	108
95	118	89	90	100	145	134	90	101	103
98	81	68	68	78	84	93	110	94	82
94	120	142	119	65	120	121	86	127	82
80	111	112	103	97	92	110	105	142	139
135	122	169	121	166	136	127	77	72	113
101	90	133	128	96	114	85	73	66	104
118	128	138	114	135	124	104	157	100	127
102	177	185	131	115	98	124	117	91	116
131	114	91	115	110	149	147	133	102	129
167	151	160	151	181	152	152	122	148	106
134	109	213	126	178	120	151	112	119	178
113	115	171	156	112	76	103	127	106	119
112	127	140	126	82	126	82	84	135	115
131	138	157	137	117	145	139	120	94	136
123	113	89	110	161	147	134	137	118	93

Board12 inner

67	71	97	107	124	105	141	106	142	112
111	125	108	105	135	123	137	120	103	103
160	138	137	158	94	154	115	135	104	128
123	93	100	123	117	106	86	86	68	91
89	107	104	81	103	111	97	111	117	122
99	100	77	95	87	73	82	84	69	105
99	112	101	73	71	73	94	82	100	104
94	59	76	88	72	66	96	75	75	80
82	95	82	80	88	68	83	82	86	80
90	89	69	64	71	58	61	61	73	81
73	90	65	59	99	85	80	86	92	91
86	98								

Board12 outer

91	105	114	97	104	116	117	95	98	89
91	72	67	88	76	67	99	87	108	99
67	76	59	96	83	93	89	64	94	71
78	67	95	76	78	74	98	79	83	81
86	68	76	81	77	84	81	78	63	68
67	60	67	78	81	70	79	69	67	89
76	74	87	98	96	80	80	81	111	95
96	95	112	163	77	68	71	75	85	68
83	89	85	68	78	86	83	73	80	70
103	102	90	101	90	114	93	107	86	110
72	76	95	112	114	124	113	115	85	70
90	120	111	112	108	88	95	70	90	96
90	107	98	105	84	90	102	80	95	79
80	94	112	113	102	98	98	109	93	85
90	92	108	102	66	62	91	82	87	82
96	97	89	69	98	88	74	69	95	91
75	80	89	97	102	71	113			

Board13

84	119	132	103	169	110	113	149	171	135
89	135	107	143	118	138	166	145	109	109
94	150	112	157	116	130	87	120	75	105
71	110	73	130	125	133	124	140	116	155
113	147	121	139	146	125	141	99	152	154
110	141	140	102	51	88	90	93	100	77
176	141	105	86	121	98	138	134	126	154
130	130	101	93	107	93	139	104	110	100
130	82	89	113	119	119	81	118	126	111
133	133	135	117	129	125	150	235	136	128
111	118	130	123	134	116	113	140	120	94
154	124	128	122	119	122	129	98	101	99
78	114	111	118	94	102	104	108	120	160
135	112	110	159	173	153	104	124	127	146
90	108	120	130	101	130	114	104	115	107
93	103	104	97	117	104	112			

Board14

112	99	104	80	116	66	97	93	106	154
106	138	91	117	115	110	100	72	80	95
113	96	103	89	92	113	106	139	118	99
81	126	75	95	83	110	85	90	117	105
109	81	87	81	85	100	108	127	115	100
125	117	116	113	118	105	99	98	104	80
70	106	98	108	118	115	126	125	100	77
121	141	91	81	94	108	106	109	142	116
143	95	113	111	119	99	121	139	126	122
118	105	119	129	126	90	108	108	140	99
116	142	132	110	98	98	80	92	95	79
94	109	100	106	113	110	103	93	94	85
92	85	78	78	84	91	86			

Board15

58	60	101	68	67	67	91	79	70	70
75	61	92	61	57	81	98	92	109	91
71	64	93	100	111	76	118	112	110	116
96	76	126	114	93	110	132	117	89	136
102	91	110	113	90	118	116	127	66	61
82	80	67	105	108	92	104	67	58	71
69	98	108	89	92	111	73	61	106	81
130	84	121	145	110	74	66	94	116	79
98	104	102	91	103	95	136	98	119	72
130	120	79	122	89	116	116	152	109	119
84	111	115	159	116	114	125	134	91	97
152	113	134	118	104	78	80	76	131	98
109	113	140	142	117	64	89	90	80	121
105	123	105	113	112	112	130	158	104	106
184	139	139	88	107	148	128	93	69	55
52	59	49	85	118	121	169	143	148	102
91									

Board16 inner

84	69	74	108	152	95	98	77	72	61
62	83	76	79	91	94	93	83	72	61
72	86	89	98	94	89	95	124	140	102
115	88	114	101	86	112	101	125	79	106
93	115	83	82	116	96	75	87	85	95
88	83	103	77	94	74	83	104	90	81
68	77	60	64	65	66	61			

Board16 outer

48	49	53	51	65	54	66	52	59	75
69	72	83	74	84	87	92	98	128	112
110	102	81	104	105	113	99	105	93	114
95	114	100	134	134	150	144	102	99	126
92	85	86	74	80	89	129	112	128	127
133	106	115	150	142	115	111	121	120	

Board17

91	122	118	65	68	132	80	100	70	62
120	97	101	101	105	109	134	167	145	131
115	125	102	79	83	114	107	119	85	98
82	77	68	54	79	55	85	91	70	87
112	85	113	115	130	108	87	124	114	123
137	122	127	104	117	88	97	76	59	66
83	75	81	108	96	98	110	100	99	103
121	98	107	103	106	99	81	106	85	98
119	128	124	92	99	76	100	109	91	57
86	98	101	120	116	113	108	110	130	136
132	132	99	160	143	121	64	90	85	97
110	114	100	97	110	117	108	104	126	109
112	106	71	84	88	109	102	121	100	119
95	107	135	119	112	94	116	125	112	79
83	103	82	92	107	89	150	107	91	98
69	76	91	69	96	98	70			

Board18

160	207	176	219	206	234	263	225	179	278
149	197	167	209	243	224	229	199	159	155
214	189	158	148	183	155	125	125	160	149
160	213	239	269	169	193	169	113	130	117
136	122	119	194	171	188	181	268	131	112
232	153	159	125	154	247	213	140	218	232
142	219	114	156	170	169	135	86	124	107
81	130	121	85	107	185	74	110	96	101
172									

Board19

111	142	142	95	147	117	110	129	132	141
211	187	208	199	178	182	232	298	156	139
198	122	121	213	218	238	203	200	107	142
140	121	170	147	129	105	129	105	140	100
145	142	158	166	120	99	125	116	134	103
101	110	96	93	97	100	123	162	111	130
183	114	85	112	98	117	118	117		

Board20 inner

146	165	145	178	117	104	188	113	173	124
164	142	155	135	114	122	102	119	153	105
163	151	125	164	116	140	121	150	135	156
147	146	114	88	73	81	85	113	104	124
132	110	119	105	100	120	118	129	106	113
121	108	84	81	83	86	84	89	105	85
84	75	75	81	94	110	97	99	97	122
105	110	111	108	98	98	83	119	102	107
112	104	109	101	109	98	106	129	128	90

Board20 outer

81	88	85	65	86	97	107	90	95	80
123	97	103	118	128	101	92	105	138	121
119	118	116	110	105	119	97	113	113	120
82	76	107	99	91	106	97	103	87	88
91	101	99	119	104	118	95	120	95	97
153	119	112	110	121	141	98	88	84	103
100	72	87	93	94	81	104	91	98	86
77	84	88	94	78	115	92	124	97	

Board21 inner

157	152	110	177	133	101	149	142	185	315
328	101	208	185	348	146	197	259	153	178
235	197	138	231	203	153	174	167	99	152
75	152	187	253	250	213	144	153	71	139
131	129	185	188	198	176	110	157	194	159
167	174	110	158	99	117	151	178	134	112
140	165	128	96	104	92	69	115	122	152
148	126	208	162						

Board21 outer

115	97	115	122	125	99	143	119	121	134
152	150	157	141	137	95	110	112	127	134
59	68	56	69	77	79	59	62	99	86
84	83	93	73	80	76	100	99	81	98
84	101	82	106	122	90	121	107	92	72
82	73	90	87	103	113	101	91	114	103
116	114	142	121	118	114	126	90	81	125
95	107	103	109	95	91	76			

Board22

143	103	178	167	218	150	203	154	88	104
141	167	214	194	301	184	200	148	176	295
143	142	156	155	128	159	151	150	136	203
141	170	206	180	98	168	247	182	160	231
155	178	136	110	137	165	197	240	205	108
96	105	215	202	225	240	206	154	156	164
120	97	151	199	228	191	199	209	215	260
264	185	192	278	235	200	221	237	225	204
180	176	167	195	131	198	233	144	116	121
136	159	187	134	93	65	92	147	194	310
232	219	293	315	299	237	214	264	229	205
270	235	198	107	84	101	186	310	356	307
198	343	330	247	359	301	328	253	197	335
296	265	282	269						

Board23

128	154	124	152	128	148	151	126	107	68
62	54	96	94	95	89	113	147	90	124
127	150	170	124	154	154	140	127	172	160
131	133	145	98	117	102	129	146	134	161
138	150	131	121	156	153	115	196	142	145
156	152	149	165	153	147	128	142	142	118
113	126	117	126	87	111	109	98	119	140
121	124	119	93	114	116	124	146	135	122
122	129	128	137	114	147	129	120	137	130
107	120	128	150	109	134	109	121	136	127
130	103	129	149	81	146	131	100	133	128
153	121	145	142	127	134	141	105	159	144
134	173	140	118	122	143	129	125	149	134
122	100	90	119	118	111	127	106	137	122
89	110	115	137	111	105	112	116	132	114
149	154	121	128	127					

Board24

148	124	98	187	96	153	297	311	335	246
289	315	277	241	300	328	345	258	429	360
272	261	309	273	181	394	267	361	305	427
430	313	183	206	157	190	206	181	295	245
186	192	191	182	184	167	190	235	216	227
313	307	265	325	354	323	379	386	344	314
295	242	209							

Board25

98	114	114	145	104	114	132	150	93	125
107	126	129	130	94	145	114	97	115	123
146	134	139	112	121	74	113	104	131	116
137	145	111	133	135	149	126	138	153	139
137	103	109	130	81	99	135	119	147	130
102	122	97	111	127	91	112	122	156	138
163	160	148	126	119	187	160	123	84	95
100	157	145	151	170	135	132	110	162	176
212	178	124	122	105	134	89	108	90	88
99	117	131	113	148	142	116	117		

Board26

110	124	122	112	100	101	69	88	72	99
95	119	90	116	114	83	86	90	102	91
90	100	106	122	103	112	82	103	93	101
92	99	84	67	66	79	66	63	65	70
71	82	79	68	83	85	106	99	98	98
96	106	91	79	87	102	100	94	80	81
74	58	59	67	57	67	78	64	62	74
62	56	53	53	54	62	74	70	66	56
69	73	66	61	67	63	60	55	65	55
67	50	69	59	49	62	67	65	71	77
90	79	81	77	67	79	72	77	79	60
66	71	69	74	70	93	91	95	90	112
99	97	94	95	90	107	110	93	75	77
60	62	70	79	69	89	71	57	75	60
69	91	82	97	95	113	105	133	132	120
101	134	107							

Board27

138	84	121	130	122	116	111	71	99	83
95	67	95	87	133	122	106	142	129	127
117	134	103	106	100	144	82	79	66	66
64	70	80	101	77	91	126	83	78	80
133	107	68	95	101	90	91	68	68	77
86	82	92	92	99	101	121	128	118	97
119	101	89	127	118	87	163	125	133	140
92	93	76	113	105	79	79	99	96	103
105	86	77	66	110	87	90	78	96	76
85	74	59	65	66	91	106	94	94	97
83	73	96	81	85	78	97	87	82	73
79	75	82	93	83	84	74	97	87	93
73	61	63	60	79	59	65	63	60	69
58	54	62	71	60	72	67	123	92	77
77	89	79	84	106	80	73	103	78	84
74	47	70	83	66	115	99	116	81	63
91	77	86	101	64	87	105	106	102	153
135	126								

Board28

116	168	161	127	99	103	179	222	192	144
138	158	132	197	191	171	181	135	75	181
247	152	135	127	132	150	159	116	118	94
152	141	177	151	179	133	139	113	137	181
160	142	178	196	127	87	98	140	96	135
128	139	133	136	94	88	112	132	122	109
97	154	144	148	132	157	153	128	89	140
123	117	84	97	134	111	72	68	70	88
68	78	129	113	123	119	129	115	101	80
124	121	75	98	82	92	101	104		

Board29

154	141	130	148	126	126	133	144	134	130
137	141	154	143	137	105	108	87	108	128
125	106	155	126	105	140	115	125	121	156
163	140	155	129	123	113	126	112	190	153
178	156	143	117	116	114	144	137	84	133
119	146	122	155	141	158	145	194	140	196
152	131	202	201	131	119	159	159	203	176
164	119	156	145	140	132	173	198	136	133
118	117	113	126	141	156	161	136	142	144
123	186	135	164	113	183	167	149	106	120
130	125	94	108	137	130	117	143	116	85
98	127	100	131	136	146	167	126	155	120
149	97	134	108	104	124	169	139	140	140
138	117	122							

Board30

114	183	166	179	155	132	155	114	111	135
157	147	199	179	203	206	177	167	170	174
202	133	156	172	184	128	151	98	137	131
103	136	100	136	148	179	119	144	91	119
129	144	144	121	113	145	142	164	195	151
140	169	184	187	104	103	108	148	107	108
139	102	110	97	125	110	97	82	94	90
146	124	89	105	87	110	111	130	85	115
74	85	73	93	123	95	131	121	117	154
158	125	113	135	134	85	87	98	118	76
68	87	100	114	84	72	90	69	67	78
66	89	74	102	107	107	104	113	71	81
112	100	96	86	108	103	110	92	126	156
109	80	70	89	96	82	89	74		

Board31

103	131	125	124	99	127	155	99	107	94
76	94	76	69	59	79	67	62	54	51
61	61	56	64	63	79	72	66	76	71
85	131	90	90	123	146	137	90	78	102
95	122	117	75	76	75	76	81	84	101
125	94	116	129	115	167	169	158	112	94
111	98	81	106	87	100	84	71	91	81
70	94	88	76	74	88	73	88	81	105
101	91	83	108	100	80	129	88	119	89
118	116	97	72	64	91	80	96	80	85
56	87	85	69	74	62	65	59	66	68
64	70	104	89	74	102	102	91	71	74
79	115	61	82	82	113	60	80	102	92
78	100	81	79	72	68	90	72		

Board32

186	166	218	162	186	150	144	129	178	146
188	171	107	150	108	143	109	131	153	142
132	135	128	92	71	78	106	99	82	117
142	102	91	98	94	123	136	160	144	98
111	93	103	80	124	82	84	89	101	83
80	77	113	115	165	136	131	101	116	170
115	138	141	217	149	119	128	189	153	165
159	129	114	144	117	141	157	147	110	132
158	122	121	100	107	111	92	88	106	86
106	136	101	151	104	106	99	83	143	114
93	106	120	124	95	91	71	93	96	78
92	98	92	91	102	81	93	98	68	77
95	83	76	108	103	127	97	131	114	131
91	108	81	181	118	128	102	134	94	117
111	104	107	133	98	112	98	76	112	94
99	115	130	116	84	83	105	89	94	98
93	109	101	97	98	86	128	106	105	102
107	99	96	62	67	103	70	76	79	121
89	82	72	96						

Board33

112	89	133	98	118	85	94	96	102	81
101	102	90	111	102	92	119	108	138	129
89	117	101	101	111	143	140	171	145	109
76	79	121	94	89	107	133	105	119	127
109	161	129	80	100	91	110	117	123	124
117	121	93	118	113	99	115	102	128	113
108	118	86	81	71	72	90	90	94	83
75	96	127	90	63	67	76	89	85	87
88	94	104	86	92	122	119	98	105	86
105	93	126	81	103	91	88	100	99	119
111	134	122	108	103	121	118	128	127	116
138	141	131							

Board34

275	203	196	206	179	197	162	166	191	217
199	183	194	155	243	191	223	279	226	204
225	241	187	246	206	262	237	194	208	160
150	149	170	169	171	166	155	177	183	197
187	168	173	180	127	196	156	136	168	174
217	158	175	174	189	158	162	139	192	158
192	174	182	143	132	188	184	134	194	158
145	125	113	147	151	134	128	125	115	114
123	117	79	88	75	87	82	80	124	117
125	147	113	106	131	128	138	125	115	112
134	148	104	75	86	84	110			

Board35

153	181	185	201	184	255	216	229	228	221
192	217	166	237	276	302	299	266	250	273
341	220	233	240	219	113	153	192	210	196
145	206	186	264	218	262	205	170	184	187
163	137	152	219	215	172	224	227	201	128
251	152	200	104	142	165	169	87	114	145
151	188	144	186	185	194	185	160	221	199
165	128	139	144	119	183	152	121	177	183
211	225	177	201	234	229	191			

Board36

138	142	106	80	78	80	100	90	80	86
91	71	100	162	126	162	138	162	165	167
172	205	191	160	130	156	165	141	155	140
169	131	112	133	123	94	135	135	125	123
152	128	168	134	114	147	111	113	148	157
118	179	118	184	140	204	185	131	108	108
96	110	88	125	100	112	106	122	114	107
123	125	93	154	150	132	194	136	140	145
112	130	166	98	104	80	118	135	136	142
137	101	115	155	148	113	126	144	96	110
96	112	83	68	82	103	104	104	77	71
58	59	70	86	93	70	135	123	133	148
145	98	84	132	138	106	98	103	129	138
123	101	122	96	91	64	97	105	90	81
81	62	80							

Board37

146	121	135	130	151	177	177	180	186	95
77	147	69	79	83	80	135	159	165	125
77	113	141	163	95	112	106	101	89	66
71	94	97	127	91	104	110	107	101	119
72	106	134	126	96	88	78	71	120	121
121	123	90	115	91	93	98	127	116	83
93	114	83	61	66	48	55	86	75	77
88	88	88	95	101	121	154	135	97	105
112	83	88	73	50	90	81	83	101	103
76	82	91	124	95	90	111	108	112	127
128	118	114	100	91	110	133	108	142	117
98	106	114	121	94	118	144	100	70	49
64	62	77	71	103	102	112	80	73	68
86	77	87	79	95	121	87	52	92	74
98	74	90	104	64	44	48	50	77	54
50	73	83	65	66	55	71	65	75	74
86	77	68	79	66	107	90	96	87	71
51	46	53	81	65	86	114	87	59	49
56	62	64	79	72	54	55	40	61	46
54	53	61	53	43	35	43	52	55	63
59	56	70	106	108	100	74	82	76	77
102	91	86	66	83	96	76	46		

Board38

195	183	208	190	229	222	185	161	112	217
144	157	181	178	142	165	186	190	193	167
222	239	179	209	186	139	161	219	231	151
142	155	214	123	186	194	223	264	291	192
159	154	196	211	144	85	112	94	119	97
157	139	153	164	167	136	135	122	133	103
211	163	130	148	147	169	150	186	160	214
95	105	107	153	140	169	179	138	117	136
169	132	165	196	174	85	85	90	138	111
86	151	150	146	95	96	97	76	99	125
119	128	128	144	139	157	128	167	87	98
154	147	123	129	106	102	141	92	86	100
78									

Board39

212	233	203	233	156	184	205	218	201	249
191	240	206	251	243	171	238	199	185	172
186	168	198	177	172	140	152	184	124	124
147	171	154	146	146	121	135	115	151	173
156	128	169	175	123	164	163	144	167	195
197	156	117	137	159	159	143	153	132	172
187	190	140	158	176	155	80	145	167	155
164	154	218	196	187	170	134	111	142	114
184	148	164	144	130	110	131	154	145	152
170	169	123	138	139	222	115	174	178	195
194	172	119	162	138	155	141	142	91	104

Board40

283	185	273	221	264	166	250	205	134	157
213	234	156	275	207	218	150	103	88	174
138	134	188	179	160	193	145	163	218	162
160	144	235	241	142	133	168	148	146	135
139	119	171	138	145	122	125	161	162	167
216	208	153	175	144	158	158	152	109	96
114	112	110	134	131	179	153	155	130	131
166	153	149	173	138	97	93	86	146	123
112	119	134	115	155	93	94	87	112	127
125	125	132	170	147	145	141	143	125	112
165	131	119	101	110	160	130	77	82	89
84	91	88							

Board41

232	219	234	236	356	225	262	274	369	392
305	204	155	177	147	123	125	156	108	123
144	125	134	122	128	105	142	159	147	171
208	292	206	218	175	199	147	126	173	222
215	169	167	172	167	129	157	153	152	186
153	126	109							

Board42 inner

84	51	66	57	53	124	99	128	105	123
100	85	67	71	84	92	69	72	81	78
92	117	97	100	107	103	77	73	87	96
84	116	102	103	66	84	107	93	109	106
73	80	80	90	86	102	54	74	91	93
69	60	48	40	46	53	61	65	68	63
77	82	111	108	120	122	75	80	80	

Board42 outer

59	62	57	58	84	76	56	50	45	44
53	63	59	58	59	64	65	80	96	76
117	92	120	94	104	126	107	137	109	65
73	93	108	97	117	108	96	87	123	113
109	114	123	95	87	82	58	105	89	77
113	94	98	111	88	98	124	98	109	88
119	128	97	62	88	97	103	66	89	92
82	78	83	96	81	78	83	68	103	108
72	103	117	101	110	123	113	116	78	85
89	100	97	114	119	133	107	106	120	97
111	114	114	74	70	51	98	110	109	94
113	117	84	86	102	85	99	92	69	80
81	83								

Board43

95	99	98	173	131	130	131	131	111	104
83	100	79	100	81	72	95	113	119	121
123	68	69	71	62	83	76	75	94	116
110	108	112	118	137	112	129	106	111	144
103	83	83	83	82	77	58	89	79	73
73	84	67	80	91	82	114	124	102	103
117	140	93	111	103	101	87	94	98	146
133	139	129	111	108	106	119	119	131	136
113	98	82	86	123	116	109	160	129	163
123	107	107	125	94	104	99	102	124	119
119	96	136	136	120	95	127	113	88	73
100	116								

Board44 inner

102	123	97	91	92	120	116	81	78	55
64	61	66	70	105	90	95	139	141	92
78	54	55	57	77	67	85	99	111	149
106	115	130	169	153	102	105	122	142	138
104	100	111	134	166	127	108	73	91	113
163	91	62	77	78	82	98	114	106	118
98	141	123	138	137	116	147	110	88	95

Board44 outer

155	134	92	104	129	114	112	134	117	132
116	108	63	90	89	105	107	107	96	103
108	95	133	91	124	104	121	141	127	94
97	113	120	105	113	96	88	94	84	76
67	88	80	61	115	100	97	115	101	144
97	113	116	129	90	116	103	100	105	120
98	98	105	105	127	108	103	104	104	63
70	81	111	96	105	136	108	136	130	93
75	66	81	69	86	76				

Board45

113	85	108	98	80	88	79	73	93	83
103	138	161	204	201	150	139	134	158	165
198	253	217	253	146	103	104	159	105	131
239	283	322	216	218	242	230	217	261	300
299	241	340	295	211	210	247	179	166	322
202	329	261	362	339	221	154	162	122	133
141	139	223	197	136	152	152	127	139	132
133	190	162	183	256	238	212	276	331	239
291	236	242	251	207	200	262	225	205	193

Board46

294	209	180	139	88	78	71	61	56	88
82	99	115	128	100	64	124	70	63	83
122	186	115	108	125	63	50	61	76	55
62	61	66	87	71	105	106	67	89	103
164	157	115	101	105	74	80	109	133	90
122	96	89	88	93	91	70	62	88	139
156	151	98	101	104	149	136	119	77	70
87	68	82	99	109	78	76	67	79	82
82	96	64	95	97	97	71	62	63	91
90	99	85	88	100	71	57	98	106	114
53	72	83	97	99	90	58	95	83	85
67	59	75	52	78	66	58	58	60	61
55	54	61	45	39	63	42	43	46	57
52	51	41	46	40	45	47	57	41	41
62	52	40	44	54	46	53	61	64	63
53	59	52	67	49	41	44	59	50	71
50	65	49	52	50	53	54	63	80	69
81	62	91	49	46	55	67	70	60	64
62	65	71							

Board47

112	102	72	105	68	101	90	88	143	148
133	229	152	181	176	162	106	152	142	147
152	86	105	121	126	167	102	117	137	73
75	78	91	102	106	142	132	107	113	80
118	100	143	108	89	104	98	89	93	104
110	116	143	110	99	60	73	68	67	72
83	78	83	95	83	98	109	125	196	109
88	77	87	69	89	106	87	98	91	97
116	98	77	109	105	123	103	70	97	90
83	113	132	123	156	87	105	99	90	130
111	111	131	135	124	152	116	125	105	136
94	85	107	95	85	76	72	83	84	126
87	95	107	96	123	101	91	91	98	96
136	128	135	107	156	118	97	69	88	89
90	107	99	87	92	84	88	75	69	72
71	84	80	98	99	113	111	152	119	115
104	126	82	80	87	131	95	118	98	89
77	90	105	79	89	89	88	65	65	62
67	59	57	62	69	61	65	69	69	48
54	61	53	62	66	77	74	59	70	76
62	63	82	73	62	57	72	66	88	76
78	84	97	65						

Board48

135	200	207	241	228	178	207	174	137	199
197	196	246	179	127	189	145	156	149	188
117	102	81	116	107	97	85	82	132	141
162	157	219	190	174	168	100	127	199	116
164	91	120	109	132	102	108	105	129	142
154	132	184	135	96	181	119	108	149	125
91	102	54	86	69	85	106	71	48	37
40	73	84	85	113	99	107	102	136	150
95	84	76	100	93	108	141	103	114	92
66	52	60	68	67	90	89	94	78	92
93	101	89							

Board49

72	57	58	82	60	78	98	83	103	98
106	106	57	91	85	80	108	106	112	104
93	84	103	109	103	94	101	80	65	55
83	85	82	107	94	98	118	85	95	79
98	104	107	97	102	92	90	90	99	89
110	109	86	88	89	98	81	100	112	101
97	122	122	83	78	77	75	83	75	99
97	90	92	91	76	88	89	100	68	79
82	60	78	79	57	81	81	82	116	97
83	85	89	79	87	79	100	95	91	109
112	99	132	103	130	111	98	102	82	95
103	84	88	94	81	98	99	96	67	74
73	75	62	82	82	96	83	85	66	82
74	89	78	79	71	81	81	65	79	77
82	61	85	100	85	64	76	92	77	90
99	78	66	89	67	68	66	60	72	57
81	71	78	72	79	80	88	86	69	71
63	76	64	55						

Board50

153	142	121	127	152	107	108	114	115	146
108	141	179	137	99	108	120	90	118	160
125	178	184	117	102	87	86	81	103	85
114	107	105	96	116	116	122	165	167	157
136	176	130	116	127	110	191	194	125	160
136	106	137	184	167	165	127	175	176	135
182	164	158	199	153	190	162	207	146	151
148	118	174	170	177	147	122	184	172	96
78	135	142	132	148	140	99	149	106	97
109	118	115							

Board51

130	174	180	170	141	156	149	142	184	185
137	152	182	272	108	155	138	169	180	173
205	172	167	207	193	171	154	210	213	140
143	148	176	193	131	118	127	177	157	164
173	112	134	150	91	145	179	137	155	120
145	143	155	131	177	115	150	151	185	215
236	225	205	142	194	224	196			

Board52

96	94	92	93	122	104	132	94	71	61
73	98	89	80	84	94	102	65	81	165
213	160	181	214	259	150	89	149	179	134
94	129	92	87	92	129	120	107	112	108
83	141	126	117	127	67	145	116	160	122
118	86	71	118	300	136	150	149	130	79
106	132	131	120	149	112	84	91	64	113
64	83	141	153	134	69	82	90	76	65
75	81	84	91	167	120	119	114	98	96
75	77	92	80	79	102	108	74	94	94
144	116	154	159	226	183	123	116	122	145

Board53

110	91	82	115	105	110	84	58	49	43
56	59	57	63	73	92	83	83	92	72
117	89	84	79	69	55	49	56	75	80
63	96	82	71	72	86	91	95	88	88
82	98	115	152	78	98	99	110	114	127
113	99	124	128	110	118	99	114	135	83
126	72	55	82	69	67	108	77	74	62
77	61	79	75	97	91	145	92	82	68
63	55	56	81	67	133	139	76	78	72
91	107	58	67	84	78	54	76	113	83
88	62	53	100	76	102	108	98	141	135
144	78	128	70	73	99	120	112	124	104
130	133	90	99	98	97	117	95	75	85
87	116	97	81	107	91	115	85	77	149
94	114	125	70	71	85	168	140	99	104
125	102	78	135	82	98	70	80	132	117
103	109	94	91	67	71	137	159	130	138
111	79	78	64						

Board54

279	225	338	271	260	253	263	177	118	170
198	139	152	154	147	163	215	196	151	129
196	154	110	151	183	129	160	140	142	115
120	132	187	163	159	185	186	162	187	177
177	153	196	191	135	127	158	177	179	131
145	114	152	128	168	132	176	179	194	93
176	207	162	162	151	188	160	197	163	145
118	108	125	138	116	166	173	145	142	156
197	173	178	172	148	104	117	106	140	69
103	164	140	130	111	91	112	100	114	136
113	124	120	145	122	154	193	150	129	128
152	153	132	109	143	170	151	123	143	

Board55

100	107	102	87	112	98	96	99	91	110
101	107	110	131	85	143	120	106	131	120
125	114	146	151	90	103	128	95	105	103
99	98	88	113	108	104	79	106	96	75
78	73	84	88	89	77	92	79	106	93
86	112	78	113	86	99	108	99	85	74
82	89	79	93	84	84	75	68	61	60
60	69	67	85	74	73	90	91	113	89
94	109	108	81	94	86	119	91	86	83
93	83	83	117	86	79	89	88	83	86
72	101	91	92	102	108	110	87	66	100
74	87	134	88	94	91				

Board56

110	184	174	223	177	155	93	125	107	139
118	124	126	101	96	147	106	94	129	74
104	64	122	90	97	86	113	89	88	97
151	145	162	146	196	189	160	119	120	122
143	108	92	96	156	88	94	113	96	103
122	92	132	112	108	113	104	96	122	148
108	139	109	84	103	105	121	113	121	126
107	85	127	101	105	109	111	91	133	104
109	73	76	89	101	144	111	96	105	109
110	116	84	101	99	141	91	133	143	110
114	81	86	71	98	63	93	70	127	159
98	113	105	149	136	146	105	124	119	136
140	134	113	121	99	121	92	95	87	100
102	111	85	152	134	132	140	121		

Board57

104	88	103	118	105	67	81	58	73	79
83	91	85	118	107	74	87	88	121	124
108	118	104	123	110	122	88	116	145	153
103	127	86	77	59	57	63	74	77	86
91	90	78	84	80	80	130	94	90	86
86	73	93	68	88	111	111	108	122	97
64	70	96	106	130	130	112	98	100	109
130	132	101	93	105	124	96	88	71	79
100	90	101	94	86	60	58	81	55	69
79	80	66	89	52	69	83	69	58	46
41	61	71	59	50	68	55	67	88	62
55	57	61	94	82	59	56	78	99	58
54	72	84	58	57	67	77	76	86	68
89	110	73	99	101	86	100	115	105	94
84	69	91	97	67	99	104	105	89	78
102	85	86	116	73	64	67	51	76	52
62	52	72	85	79	74	73	61	54	62
62	59	52	51	74	71	98	95	95	59
63	77	103	80	90	97	106	71	78	76
101	98	101	144	154	142	86	74		

Board58

98	87	119	79	113	82	104	126	86	127
92	142	139	174	123	143	91	86	101	152
88	144	114	142	94	108	119	98	104	126
128	86	96	95	131	71	60	113	120	126
101	72	74	72	79	100	125	103	77	89
95	127	125	117	117	107	127	107	104	91
102	137	115	96	85					

Board59

136	155	190	161	167	162	174	184	163	176
235	195	142	198	194	236	221	210	179	237
180	186	174	250	161	188	200	195	190	203
162	160	175	159	199	141	84	122	129	114
178	169	143	140	125	104	127	146	158	183
151	169	187	161	158	188	150	165	132	168
157	125	86	121	154	147	118	137	122	133
123	127	109	93	94	123	92	139	145	139
150	120	119	111	155	111	129	93	120	115
135	134	124	107	154	135	162	125	133	130
111	111	104	98	100	125	87	97	126	113
150	104	78	103	95	90	101	111	101	103
108	121	101	109	93	127	107	119	103	123
111	95	128	120	86	109	117	107	134	95
133	132	104	105						

Board60

128	146	105	137	177	127	155	117	129	144
115	92	82	88	113	95	96	103	104	112
121	98	70	91	83	75	103	80	69	77
60	78	60	66	54	66	60	70	55	66
63	96	62	68	72	67	86	49	66	61
60	49	49	49	62	50	49	62	69	69
56	55	68	59	60	71	54	78	57	92
65	76	76	93	80	71	96	65	109	90
108	131	111	80	98	80	80	67	65	78
84	108	83	86	99	97	87	108	109	104
128	132	89	107	118	148	150	160	151	141
138	134	127	152	151					

Board61

212	229	252	221	219	205	186	204	189	73
87	188	88	171	123	175	157	102	218	188
216	174	166	137	148	96	101	148	222	243
209	211	194	175	163	185	183	149	141	133
99	62	139	101	168	68	94	123	69	120
92	60	124	156	136	74	86	171	144	172
177	155	105	138	99	52	86	98	90	133
122	122	138	171	105	103	161	151	146	140
111	108	117	139	185	143	294	147	142	187
164	218	145	320	182	164	120	98	77	69
88	81	56	69	86	107	112	124	150	123
87	133	158	216	145	153	150	117	172	95
131	166	116	161	126	106	148	122	185	160
161	63	156	144	146	132	159	164	151	170
145	141	180	142	107	187	142	95	100	69
128	125	120	98	87	108				

Board62

95	143	146	153	144	112	135	99	82	114
185	141	116	109	108	122	75	103	102	131
157	162	163	125	137	86	137	156	204	126
156	192	148	197	183	199	143	115	131	164
135	98	88	88	96	85	75	94	92	83
77	84	107	107	124	134	73	185	142	162
173	115	106	103	123	90	95	79	83	75
175	121	99	114	119	77	76	82	105	86
117	89								

Board63

304	234	261	221	208	237	352	264	252	332
221	327	272	222	216	224	192	214	222	251
232	203	199	204	174	153	254	214	231	260
194	160	200	193	280	254	208	253	213	268
240	207	214	159	204	215	174	136	130	202
235	223	208	199	134	152	165	149	152	158
189	233	180	128	144	122	131	160	106	164
218	223	174	142	129	123	133	184	114	132
130	144	135	126	178	253	170	251	184	237
155	192								

Board64

115	92	79	81	81	76	76	106	99	61
86	101	73	68	80	70	73	84	92	100
82	130	78	69	92	72	109	85	74	69
80	74	69	73	81	78	63	59	44	36
72	61	66	74	75	68	52	38	48	71
71	66	73	79	92	72	51	78	83	81
60	93	105	75	67	65	100	100	69	70
67	88	74	100	72	66	81	94	65	120
71	66	89	66	119	87	127	59	65	66
54	56	97	74	97	87	88	54	72	77
65	82	90	74	80	58	64	75	56	56
57	61	81	59	49	49	62	49	78	69
66	69	72	65	84	96	80	66	63	77
75	64	53	48	67	49	53	49	49	46
50	73	65	65	61	63	55	55	51	40
49	54	60	64	71	59	50	53	57	71
101	112	117	131	113	104				

Board65

108	88	69	62	73	88	116	114	110	197
96	74	91	123	144	89	118	129	71	79
93	68	74	88	106	91	92	64	66	66
77	71	65	60	89	95	87	112	78	113
82	110	99	105	122	151	132	128	106	131
113	106	84	91	107	73	78	100	92	73
94	105	86	90	71	55	76	85	76	84
75	70	96	78	72	102	71	76	65	112
116	72	60	61	81	85	67	84	89	58
75	80	89	119	98	94	83	134	94	79
128	122	189	160	141	121	86	71	72	65
124	98	104	90	154	83	79	125	104	109
137	130	76	70	41	56	70	84	78	91
88	93	69	82	68	69	80	73	70	68
94	75	87	113	120	72	109	142	108	92
82	84	115	108	80	60	65	74	72	76
77	86	92	98	88	79	76	83		

Board66

98	82	62	98	91	81	111	96	93	87
82	105	105	81	112	88	104	105	93	97
107	111	74	79	100	95	85	103	91	100
56	66	80	67	86	87	93	77	78	58
71	88	80	74	83	84	86	95	72	69
78	60	79	58	77	83	75	51	71	90
85	86	107	78	92	91	84	92	89	82
87	52	98	102	75	102	87	93	97	116
81	79	94	85	70	88				

Board67

210	243	319	339	325	292	167	146	168	121
155	181	176	339	327	235	232	176	138	111
180	263	241	306	176	229	185	169	269	179
244	174	296	225	248	146	127	183	228	157
245	250	259	134	149	143	163	178	152	114
254	216	178	201	139	124	136	154	115	130
120	87	140	174	89	171				

Board68

110	188	174	192	188	235	189	149	99	163
114	148	170	218	211	220	211	162	141	186
224	173	95	108	157	195	137	163	163	144
123	142	108	119	121	133	120	122	205	140
176	142	178	179	185	148	179	118	125	117
165	109	151	154	147	129	138	175	168	139
160	153	85	97	96	146	58	104	92	98
109	93	79	65	48	65	91	86	99	90
123	136	127	131	126	116	120	126	129	148
98	108	124	122	74	130	125	121	136	74
127	98	88							

Board69

59	94	71	82	48	76	80	88	73	81
79	92	77	92	66	118	133	91	98	89
123	104	102	115	102	129	75	73	77	78
78	76	69	65	59	40	61	59	64	61
62	68	61	62	47	60	92	77	72	89
75	75	80	82	83	90	79	90	72	94
77	73	83	79	62	48	81	79	71	73
63	55	74	71	66	59	57	61	53	40
35	50	66	67	74	82	67	90	74	71
55	66	71	53	54	54	52	29	34	34
42	75	81	80	87	79	106	82	80	75
83	72	76	86	78	64	50	87	77	112
93	89	70	64	68	79	95	88	81	91
107	87	80	68	48	45	70	64	89	100
126	92	101	89						

Board70

260	291	241	236	192	203	172	186	171	236
266	245	246	269	219	194	226	202	224	243
285	244	181	205	202	172	143	230	200	182
203	168	172	163	145	161	161	143	167	133
221	189	173	144	160	223	219	186	160	240
362	238	149	149	183	177	108	120	168	174
153	193	179	180	173	176	145	238	233	178
202	161	191	209	253	190	206	182	163	187
271	225	211	233	233	161	167	187	229	260
194	160	176	203	171	221	160	143	212	253

Board71 inner

336	167	218	165	119	187	193	193	278	318
232	159	179	263	257	205	147	227	129	190
182	145	137	155	126	126	161	166	159	131
127	119	114	134	150	194	116	152	160	112
96	134	195	140	141	109	97	115	115	120
124	124	136	157	167	196	149	140	156	159
110	108	116	104						

Board71 outer

161	112	105	78	167	158	149	184	153	180
101	95	118	75	97	91	105	140	153	96
98	128	99	100	111	151	115	99	108	139
127	128	139	168	160	112	92	106	123	102
96	130	126	172	142	167	130	171	203	198
170	208	178	122	164					

Board72 inner

140	91	85	76	62	61	141	124	112	103
71	89	72	93	89	93	93	115	86	104
74	115	109	128	63	100	96	85	108	173
146	117	119	109	122	114	106	123	104	116
120	89	100	103	101	123	105	101	80	75
93	108	77	104	134	112	84	57	52	61
64	71	73	79	95	107	85	89	128	113
158	101	113	133	86	65				

Board72 outer

100	149	135	138	119	95	110	95	108	105
104	106	118	74	67	53	89	55	75	58
83	64	71	58	49	56	51	46	54	53
70	103	97	84	103	107	109	82	142	144
121	82	100	153	207	95	90	89	138	88
74	131	108	126	167	177	119	96	83	74
68	88	73	94	93	69	66	144	125	122
145	138	152							

Board73

80	60	91	60	55	38	71	64	75	68
64	58	86	70	71	83	91	86	53	67
63	82	67	67	74	65	53	91	72	66
50	56	67	76	76	89	66	72	64	55
78	96	82	100	120	80	88	95	84	61
91	99	95	102	72	81	58	71	87	86
90	91	110	112	107	111	94	84	85	100
96	73	79	70	67	90	75	96	102	120
124	86	129	113	108	79	88	92	70	67
79	92	67	72	83	81	73	81	100	75
82	113								

Board74

149	147	113	139	109	132	116	141	110	156
116	103	109	134	131	133	82	100	149	135
134	118	138	180	112	105	119	126	105	124
100	124	127	124	123	110	117	102	103	87
130	107	103	124	133	163	137	177	151	161
110	145	116	172	154	162	152	154	121	144
177	139								

Board75

225	175	276	259	281	264	255	202	234	366
235	297	241	224	240	344	226	312	196	224
240	323	277	295	286	266	212	254	357	343
370	398	351	271	315	254	338	318	277	328
327	350	214	303	289	234	296	300	261	251
263	340	334	291	354	308	297	219	385	345
250	241	203	347	276	221				

Board76

148	142	187	161	110	142	131	131	129	110
100	79	86	127	136	88	118	115	103	99
115	115	132	89	118	171	143	90	77	116
109	75	79	79	105	111	117	86	127	99
119	120	172	138	134	156	146	187	126	116
120	177	94	121	166	174	122	182	152	204
121	124	147	176	116	188	144	112	116	116
124									