DENDROCHRONOLOGICAL ANALYSIS OF OAK TIMBERS FROM THE WHITE BEAR, MIDDLEWICH, CHESHIRE.

Tree-Ring Services Report: CWWB/26/11

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SUMMARY

Six of the fifteen samples taken from The White Bear are dated. All six samples match together to form a 169-year site chronology called MIDWH-W2 which spans AD 1456 to AD 1624. Two precise felling dates in the springs of AD 1619 and AD 1625, together with three compatible felling-date ranges, indicate that construction is likely to have occurred in AD 1625, or soon after. The six year range between the two precise felling dates suggests that some stockpiled and/or windfall timber was used in the construction.

The average age of the source trees used in the construction is 73 years. Cross-matching against individual buildings and area reference chronologies is sufficiently high to indicate that the dated timbers probably came from local sources. Four of the samples dated show signs of management, the clearest sample shows a management practice such as pollarding or shredding (the lopping of branches usually for fodder) on a mean 15 year cycle.

KEYWORDS

Dendrochronology, 17th Century, Standing building, Cheshire, Middlewich.

Figures

Tables

Photos

INTRODUCTION

There is an increasing interest in Britain's past as evinced by such television programmes as "Time Team" and "The House Detectives", which both promote and respond to this interest. More and more people wish to know precisely when ancient buildings were constructed in order to better understand the history of the land in which we live. However, although there is some ability to date a building on stylistic grounds, a precise date is rarely known except when there is a date-stone or documentary evidence.

The advent of dendrochronology (tree-ring dating) is changing this scenario, at least for buildings with timbers containing sufficient rings for analysis. The science is simple in concept. The width of a tree's growth rings varies from year to year, so that each series of years has a unique pattern of narrow and wide rings. We now know in detail the pattern of rings shown by oak trees in England for at least the last 2000 years, and there is some work in progress on other species. Small cores of wood taken from the structural timbers of a building show the pattern of rings laid down during the lifetime of the trees from which the timbers were cut. If this pattern is then compared with "master chronologies" it is often possible to identify the felling date of the trees with astonishing accuracy. Where bark is present, it is possible to give a precise year, sometimes even the season of the year. We know that oak for building was almost always used "green", (unseasoned, not having been felled and prepared until required), so construction dates can be determined in which we can place considerable confidence.

Recording Timber-Framed Buildings

National trends in building activity inevitably conceal regional differences that can only be explained by detailed local studies. The Royal Commission on the Historical Monuments of England (RCHME) has analysed 53 medieval buildings in Kent (Pearson 1994). Hampshire County Council has analysed well over 100 buildings in the county (Roberts 2003). These projects utilize the specific dates provided by tree-ring analysis to refine the typological and stylistic dating of buildings.

Harris (1978) provides a useful introduction to the study of timber-framed buildings, while Brunskill (2000) details the study of vernacular architecture. Alcock's (1996) glossary provides illustrative drawings which are particularly useful in facilitating the naming of timbers in a building.

Figure 1: Area location map

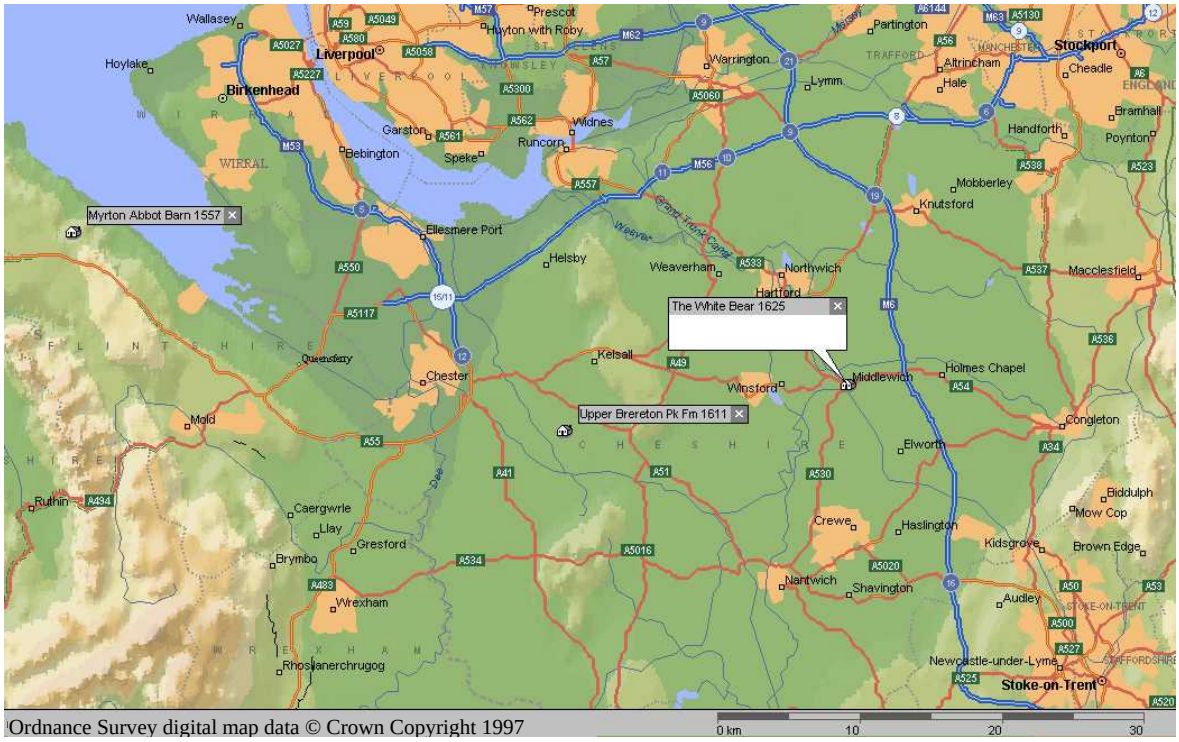
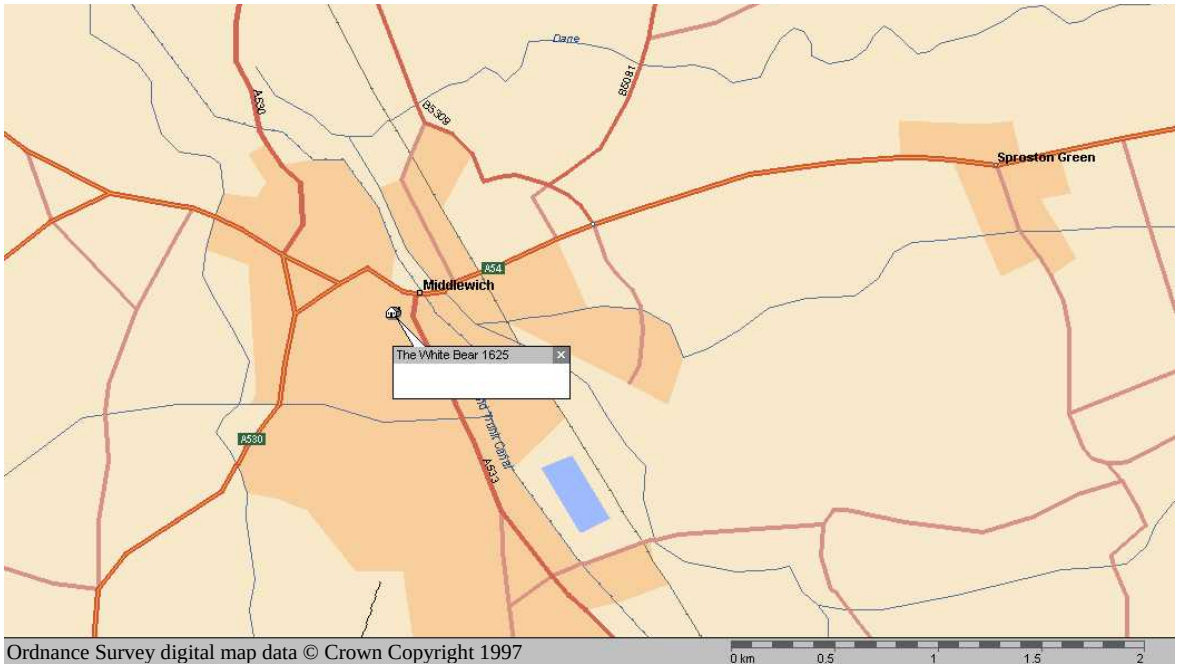


Figure 2: Site location map



The White Bear (NGR: SJ 7026 6629).

The White Bear located on Wheelock Street, Middlewich is a two storey brick building with a mock Tudor timber façade to the first floor. There are a few surviving fragments of original timber-frame. The building appeared to be four bay, but no detailed recording of the building was undertaken.

Photo 1: The White Bear – south-west aspect

Photo 2: The White Bear Barn – south-east aspect

Objective of the Analysis

The objective of this analysis was to provide dendrochronological evidence to date the primary construction phase of the building.

Dendrochronological Assessment

The White Bear was visited on the 20th September 2011 when the building was undergoing refurbishment. The timbers were assessed for their potential use in dendrochronological study. Oak timbers with more than 50 rings, traces of sapwood or bark, and accessibility were the main considerations.

Three main fragments of timber-frame were located (see **Appendix I**) and all were identified to be constructed from oak. A number of timbers in trusses C and D contained more than 50 rings and retained full sapwood and were therefore selected for sampling. No samples were taken from the timbers between trusses B and D as no sapwood could be located. However, a number of *ex situ* oak timbers, (which workers at the site identified had come from bay A), contained sufficient rings for analysis, and sections were taken from these samples. The roof timbers consist of two sets of trenched purlins, but these are pine and contain insufficient rings for analysis.

METHODOLOGY

Methods employed by Tree-Ring Services in general are those described in English Heritage guidelines (Hillam 1998). Part 2 of the Guidelines is designed for large projects in conjunction with other specialist disciplines and is not applicable to the type of privately commissioned dendrochronological analysis generally conducted by Tree-Ring Services and is therefore not used. Details of the methods employed for the analysis of this building are described below.

Sampling and Preparation

Photo 3: Extraction of a core in progress

Whenever possible, timbers with more than 50 annual growth rings are selected for sampling. This is necessary to provide a pattern of rings of sufficient length to be unique to the period of time when the parent tree was growing. Timbers are sampled using purpose-made 12mm and 15mm diameter corers attached to an electric drill. Sampling is located as discreetly as possible in what appear to be original timbers and is orientated in the most suitable direction to maximize the numbers of rings for subsequent analysis. Extracted core samples are immediately taped and glued onto wooden laths on site and then labelled, ready for subsequent analysis.

Tree-ring series are revealed through sanding with progressively finer grits to a 600 abrasive grit finish to produce results suitable for measuring, see **Photo 4**. When required, for example where bands of narrow rings occur, further preparation is performed manually. Where requested, extraction holes are "made good", employing pine dowelling, wood-glue, sawdust and wood stains to restore the timbers to their original appearance.

Photo 4: An example of the tree-ring series revealed through the sanding of cores

Measuring and Cross-matching

Tree-ring series are measured under a ×20 stereo microscope to an accuracy of 0.01mm using a microcomputer-based travelling stage. All samples are measured from the centremost ring to the outermost. Samples considered unsuitable for dating purposes are then rejected. These include samples with disturbed ring series which cannot be measured due to knots or bands of extremely narrow rings, and those samples with fewer than 40 rings.

Samples of fewer than 50 rings are sometimes rejected from dendrochronological analysis because their ring patterns may not be unique (Hillam *et al.* 1987). Although this is certainly true of all ring series of fewer than 30 rings, which should not be used in dating (Mills 1988), samples with 30 to 50 rings may be dated in some circumstances (Hillam 1998). Because samples taken by Tree-Ring Services are often from listed structures, it has been felt wise to maximize the recorded amount of data, and series of 40–50 rings are included in analysis and considered for dating, usually when they match well with a

number of other series. Samples are measured twice and the two sets of measurements cross-matched and plotted visually as a check. Where series match satisfactorily they are averaged and the resulting series are used in subsequent analysis. Series containing fewer than 50 rings are suffixed '-S', and series from managed trees '-M' to help indicate that additional caution must be exercised in dating.

Cross-correlation algorithms are then employed to search for the positions where tree-ring series correlate and therefore possibly match. All statistical correlations are reported as *t*-values derived from the original CROS73 algorithm (Baillie and Pilcher 1973). A value of 3.5 or over is usually indicative of a good match as it represents the value of *t* which should occur by chance only once in every 1000 mismatches (Baillie 1982), and the higher the *t*-value the closer to congruency in the cross-matching. However, due to the remaining small risk of high *t*-values being produced by chance, all indicated correlations are further checked to ensure that corroborative high results are obtained at the same relative position against a range of independent tree-ring series. Visual comparisons of series are also employed to support or reject possible cross-matches and serve as a means of identifying measuring errors.

Timber Groups

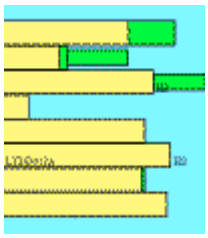
A further element of the tree-ring analysis of buildings and archaeological assemblages is the grouping of timbers within the sampled material. Inspection of *in situ* timbers may indicate that samples derive from a common timber, while common arrangements of anatomical features (knots & branching) may also indicate that samples are derived from a single tree.

Tree-ring analysis is used to support suggestions of same-tree groups between samples based on a combination of information. Timbers derived from the same tree are generally expected to have *t*-values over 10, although lower *t*-values may be produced when different radii measured from the same tree are compared. Tree-ring series producing *t*-values of 10 or above are examined to identify same-tree groups. Good comparisons of visual matching, growth rates, short and longer-term growth patterns, are combined with pith information, sapwood boundaries, bark and anatomical anomalies, to help decide whether timbers are likely to come from the same tree. Where timbers are assessed as deriving from the same tree, to avoid bias the series are averaged to produce a single tree-ring series before inclusion in the final site chronology, but inevitably some same-tree samples go undetected by dendrochronology.

Chronology Building and Cross-dating

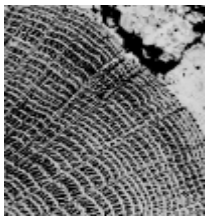
The process of cross-matching compares all tree-ring series against one another and those found to cross-match satisfactorily together are combined to create an average series. The site mean(s) and individual ring series which remain unmatched with the site mean are then tested against a range of established reference series (reference chronologies). Significant *t*-values replicated against a range of series at the same position with satisfactory visual matching are similarly used to establish cross-matches with reference chronologies. Where cross-matching is established against dated reference chronologies, calendar dates can be assigned to the site series. The dates of the first and last rings of dated series are produced as date spans. These dates should not be confused with felling dates.

Felling Dates



Series dated by the cross-dating process provide calendar year dates for the final tree-ring present in the measured timber sample. The interpretation of these dates then relies upon the nature of the final rings in the series. Where bark survives intact on a sample a felling date is given as the date of the last ring measured on the tree-ring series. Based on the completeness of the final ring it is sometimes even possible to distinguish between spring, summer or winter fellings, corresponding to approximately March to May, June to September and October to February, respectively. Where timbers were felled in either spring or summer and the final ring is incomplete and therefore not measured, allowance has to be made for the one-year discrepancy between the end of a measured series and the actual year of felling.

Sapwood Estimates

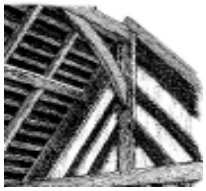


Where bark is missing from oak samples, as long as either sapwood or the heartwood/sapwood boundary have been identified, an estimated felling-date range can be calculated using the maximum and minimum number of sapwood rings that were likely to have been present. Sapwood estimates have varied over time with different data sets, geographical location and researchers. A general trend identified is that the number of sapwood rings in oak decreases from north to south and from west to east across Europe.

However, simply not enough is yet understood about sapwood variations and the mechanisms responsible for them. A generally accepted sapwood estimate of between 10 and 55 rings for British and Irish oaks (at 95% confidence) was given in 1987 (Hillam *et al.* 1987). Analysis of the increased data set available ten years later indicates a range of 10 to 46 rings to be more appropriate for England (Tyers 1998). Currently, as research in areas improves, sapwood estimates are refined and new estimates applied. Therefore, when dendrochronological dates are produced, the reference to the sapwood estimate used in its calculation should always follow.

This report applies a sapwood estimate of a minimum of 9 and maximum of 41 annual rings, which means that 19 out of every 20 trees examined is expected have between 9 and 41 sapwood rings. This sapwood estimate is currently applied to most of the south-east region and has been arrived at by Oxford Dendrochronology Laboratory (Haddon-Reece *et al.* 1990, Miles 1997). Felling-date ranges have been calculated by adding the sapwood estimate of minimum and maximum missing rings to the date of the heartwood/sapwood boundary. Felling-date ranges have been refined by the presence of surviving sapwood where appropriate, see **Table 4**. Where samples ending in heartwood were dated, "felled after dates" have been calculated by adding the minimum expected number of missing sapwood rings to the samples' final ring dates. These dates represent the earliest probable felling dates. However, the actual felling date of a tree may be decades later due to an unknown number of missing heartwood rings.

Felling Groups



It is common to find that timbers used in the construction or repair of smaller buildings, or identifiable parts of larger buildings, date into groups whose felling dates occur within a narrow range of years. These groups are called associated fellings. Where they are identified the average heartwood/sapwood boundary of the component timbers is used to calculate an overall estimated period of felling. Close location association and a short (21 years at most) range of heartwood-sapwood boundary dates are normally used to define these groups. The estimates do not assume that trees within a group were felled at the same time. However, evidence published by the Nottingham University Tree-Ring Dating Laboratory indicates that the range estimate encompasses the possible different individual felling dates (English Heritage 2001). Where bark is present within a group of timbers and other evidence does not dispute the date, it is assumed that all the trees within a felling group were felled in the same year.

Date of Construction

It is vitally important to understand that dendrochronological analysis provides dates for when trees were felled and not necessarily when their timbers were used. Green or freshly felled wood is, however, far easier to work and it is standard practice to assume that medieval timbers were felled as required and used green (Rackham 1990, Miles 1997). However, the use of previously felled timbers in vernacular construction was not uncommon, with short-term stockpiling of usually not more than 1 to 2 years (Miles 1997), and the use of leftovers or re-used timbers may certainly give rise to differences between felling dates and the date of construction where samples are analysed in isolation. A number of samples having a close range of felling dates are required from different elements of a building either to strongly indicate a single date of construction or to identify separate phases of construction.

Tree-Ring Services - Methods and Criteria

Tree-ring analysis and graphics are achieved via a dendrochronological programme suite developed by Ian Tyers of Sheffield University (Tyers 1999). Location maps are produced using *Microsoft AutoRoute Express GB 98 Auto Street Navigator*, which uses Ordnance Survey digital map data © Crown Copyright 1997. Alcock's (1996) timber-framed building nomenclature has been adopted throughout to facilitate regional comparisons.

For the analysis of a building an initial assessment is conducted with the owner and recommendations in line with English Heritage guidelines on sampling strategies made, (i.e., that a minimum of 8 to 10 samples are obtained per building or per phase). However, the final decision concerning the number of samples taken for analysis rests with the individuals who commission the analysis. It is generally beyond the scope of an analysis to describe a building in detail or to undertake the production of detailed drawings. Without the benefit of other specialist disciplines there is always the danger that re-used timbers may be inadvertently selected, and the conclusions presented in a report may be modified in the light of subsequent work.

RESULTS

Eight sections and seven core samples were taken from The White Bear on the 20th September 2011. The main timber trusses were labelled sequentially from A in the south-west corner to E1 in the north-east corner. Sampling locations are indicated on a sketch plan of the building (see **Appendix I**) and the locations of cores taken are shown in the photographs below. No photographs were taken of samples CWWB01 to CWWB04.

Photo 5: Section CWWB05

Photo 6: Section CWWB06

Photo 7: Sections CWWB07-M (far left) & CWWB08-M (inner left)

Photo 8: Core CWWB09-M

Photo 9: Cores CWWB10-S, (left), CWWB11-S (right) & CWWB12-M (middle)

Photo 10: Cores CWWB13-S (top right) CWWB14-M (bottom right) & CWWB15 (top left)

All the samples analysed were confirmed as oak (*Quercus* spp). Six samples were taken from where the sapwood appeared complete. The sapwood broke off from sample CWWB11-S during sampling, but no rings were thought lost. Five samples contained sudden and sustained periods of ring width reduction characteristic of direct management and were identified by the suffix 'M', i.e., CWWB07-M, CWWB08-M and CWWB09-M, CWWB12-M and CWWB14-M. Five series containing less than 50 rings were identified by the suffix '-S'. Samples CWWB02-S, CWWB04-S, CWWB10-S, CWWB11-S and CWWB13-S. Sample CWWB15 contained just 18 rings and therefore this sample was rejected from further analysis at this stage. A total of fourteen series were of sufficient length to be considered for cross-matching.

Three series from ex-situ timbers were found to match together (see **Table 1**).

Table 1: Cross-matching between three series from The White Bear which form the chronology MIDWH-W1.

Filenames	Start	End	CWWB03	CWWB04-S
CWWB02-S	15	51	7.03	3.54
CWWB03	1	51		4.63
CWWB04-S	7	51		

KEY: - = *t*-values less than 3.50. \ = overlap < 30 years.

Series CWWB02-S, CWWB03 and CWWB04-S were combined to form a 51-year site chronology named MIDWH-W1, but the chronology failed to cross-match with reference chronologies and therefore remains undated at this time.

Six other series were found to match together (see **Table 2**). Series CWWB05, CWWB06, CWWB07-M, CWWB08-M, CWWB09-M and CWWB12-M were combined to form a 169-year site chronology named MIDWH-W2.

Table 2: Cross-matching between six series from The White Bear which form the chronology MIDWH-W2.

Filenames	Start dates	End dates	CMWB06	CWWB07-M	CWWB08-M	CWWB09-M	CWWB12-M
CMWB05	AD1554	AD1624	6.25	\	-	-	-
CMWB06	AD1534	AD1618		\	-	-	4.14
CWWB07-M	AD1456	AD1554			-	4.16	5.39
CWWB08-M	AD1518	AD1585				4.36	7.38
CWWB09-M	AD1494	AD1587					5.27
CWWB12-M	AD1477	AD1598					

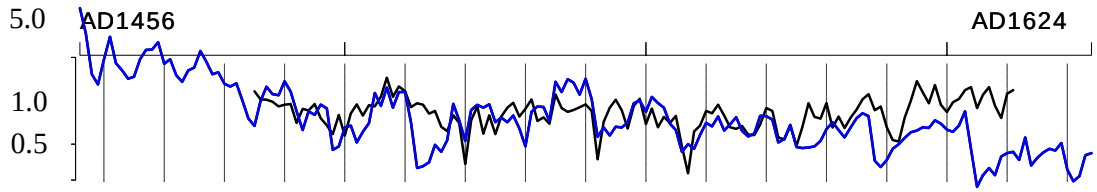
This site chronology was found to produce consistently high *t*-values against reference chronologies (**Table 3**), with the first ring of the series at AD 1456 and the final ring of the series at AD 1624.

Table 3: Dating evidence for site chronology MIDWH-W2 against reference chronologies.

MIDWH-W2 dated AD 1456 TO AD 1624					
File	**Start Date**	**End Date**	***t*-value**	**Overlap (yr.)**	**Reference chronology**
SHROP15	AD1069	AD1687	5.87	169	Shropshire county (Moir, unpublished)
EAST_MID	AD882	AD1981	5.65	169	East Midlands (Laxton and Litton 1988)
OWSTN-C1	AD1485	AD1611	5.32	127	St Andrews Church - Owston - Leicestershire (Howard *et al.* 1998)
WHTOWER7	AD1463	AD1616	5.08	154	Tower of London - London (Miles 2007)
SHPTNMLT	AD1518	AD1677	5.04	107	8 Market Place - Shepton Mallet - Somerset (Miles 2002)
SHRWCST2#	AD1498	AD1647	5.04	127	Shrewsbury Castle - Shrewsbury - Shropshire (Bridge and Miles 2005)
NWDGT-NP	AD1502	AD1607	4.83	106	Nyes Place - Newdigate - Surrey (Moir 2003)
CHARL-PF	AD1484	AD1595	4.81	112	Charlwood Place Farm – Charlwood – Surrey (Moir 2004)
ASHBURTN	AD1420	AD1616	4.79	161	Pridhamsleigh Manor & Farm - Staverton - Devon (Arnold and Howard 2008)
MILKST#	AD1353	AD1654	4.76	169	2 Milk St - Shrewsbury – Shropshire (Miles 1996)
CRATFLD2	AD1503	AD1639	4.75	122	St Marys Church - Cratfield - Suffolk (Bridge 2008)
MERTON2	AD1442	AD1608	4.58	153	Fellows Quad - Merton Collage - Oxford - Oxfordshire (Miles and Worthington 2006)

KEY: **Bold** = indicates a composite reference chronology consisting of multiple site chronologies. # = Component of the SHROP15 chronology.

Figure 3: Plot of site chronologies MIDWH-W2 (blue) and OWSTEN-C1 from St Andrews Church – Owston – Leicestershire (black), which cross-match together with a *t*-value of 5.32.



Note: The ring width (mm) is plotted on a (y axis) logarithmic scale using a common axis for both samples.

The remaining five unmatched series were individually compared against our database of reference chronologies, but all failed to cross-match and therefore remain undated at this time.

Table 4: Summary of dendrochronological analysis.

Sample	Timber and Position	Sample	Timber Conversion	Timber Dimensions (mm)	Rings	Sapwood	Average Growth Rate (mm/yr)	Sequence Date Range	Felling Date	Rings to Pith		Age Estimate
CWWB01	*Ex situ* - bay A?	Section	C2	100 x 85	69	+HS	2.26				10	79
CWWB02-S	*Ex situ* - bay A?	Section	C2	80 x 60	37	15+¼B	1.99				15	52
CWWB03	*Ex situ* - bay A?	Section	C2	80 x 75	51	21+¼B	1.08				15	67
CWWB04-S	*Ex situ* - bay A?	Section	C2	75 x 55	45	25+¼B	1.64			>	15	60
CWWB05	*Ex situ* - bay A?	Section	A2	180 x 115	71	36+¼B	1.29	AD1554-AD1624	Spring AD1625		0	80
CWWB06	*Ex situ* - bay A? - spine beam	Section	A2	225 x 225	85	18+¼B	1.89	AD1534-AD1618	Spring AD1619		0	103
CWWB07-M	Brace - truss C	Section	B2	223 x 110	99		2.37	AD1456-AD1554	after AD1566	>	0	99
CWWB08-M	Lower tiebeam - truss C	Section	?	155 x 170	68	+HS	2.27	AD1518-AD1585	AD1597-1630		15	83
CWWB09-M	Post - truss C	Core	A2	170 x 250	94	+8	1.55	AD1494-AD1587	AD1599-1632		15	109
CWWB10-S	South principal rafter	Core	A2	160 x 250	35	15	2.82				15	50
CWWB11-S	Upper tiebeam - truss C	Core	A2	170 x 150	45	+31+?B	1.05				15	60
CWWB12-M	Raking queen strut	Core	A2	210 x 110	122	5+14	1.06	AD1477-AD1598	AD1612-38	>	15	150
CWWB13-S	Tiebeam - truss D	Core	B2	210 x 150	38	+HS	2.27				15	59
CWWB14-M	Post - truss D	Core	?	180 x 120	104	+HS	1.07				15	137
CWWB15	North principal rafter - truss D	Core	?	180 x 120	18						15	51

KEY	
+	= additional information not measured on the core
(+)	= unmeasured heartwood rings at the beginning or end of the core
HS	= heartwood/sapwood boundary
?B	= probable bark
¼B	= spring bark
Bw	= winter bark
A2	= boxed heartwood & trimmed
B2	= halved & trimmed
C2	= quartered & trimmed

Note: Timber dimensions were generally taken at the core sample location and are not necessarily the maximum dimensions of the timber.

INTERPRETATION

Felling Dates

The sapwood allowance used to calculate the felling dates now discussed is presented in **Table 4**, and the bar diagram (see **Figure 4**) helps to demonstrate the findings visually.

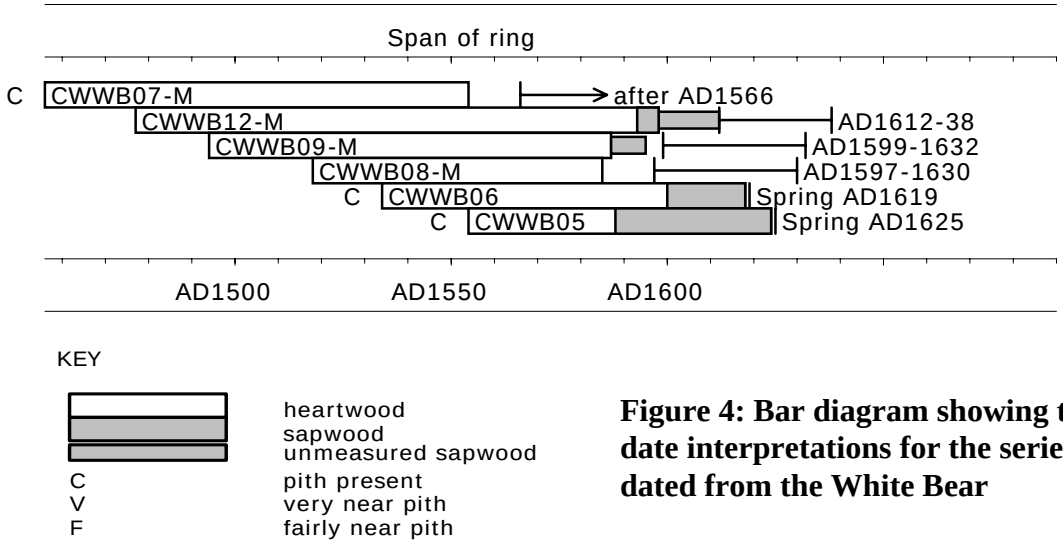


Figure 4: Bar diagram showing the date interpretations for the series dated from the White Bear

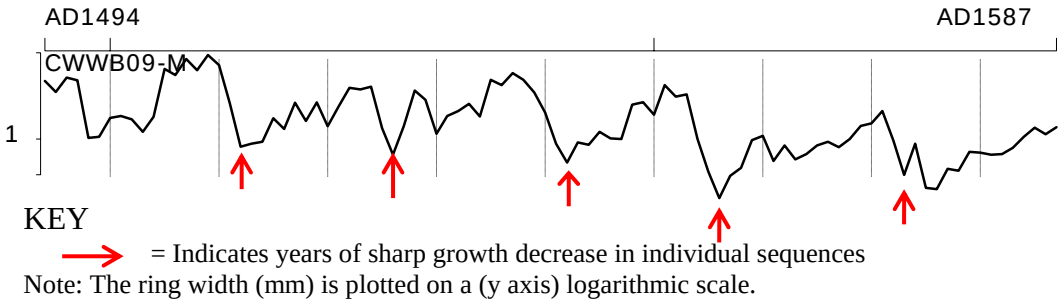
Six of the fifteen timbers sampled from The White Bear are dated, two of these samples produce precise felling dates. Under the microscope, full sapwood on samples CWWB05 and CWWB06 occurs with the partial development of the final ring, indicating that the source trees were felled in the springs of AD 1619 and AD 1625, respectively. The felling-date ranges produced from three other samples dated are compatible with these fellings, and together the evidence indicates that construction occurred in AD 1625, or soon after.

The six year range of the two precise felling dates suggests that some stockpiled and/or windfall timber was used in the construction.

Timber analysis

All the timbers sampled were oak. The average age of the source trees used in the construction is 73 years. Cross-matching against individual buildings and area reference chronologies is sufficiently high to indicate that the dated timbers probably came from local sources.

Figure 5: Ring width plot showing cycles of growth reduction.



Note: The ring width (mm) is plotted on a (y axis) logarithmic scale.

Sample CWWB09-M shows the clearest five periods of growth reduction in AD 1511, AD 1525, AD 1540, AD 1554 & AD1572, with periods of 14, 15, 14 and 18 years, respectively between (**see Figure 5**). This pattern of ring-width reduction and recovery is characteristic of a management practice such as pollarding or shredding (the lopping of branches usually for fodder) on a mean 15 year cycle.

CONCLUSIONS

Six of the fifteen samples taken from The White Bear are dated. All six samples match together to form a 169-year site chronology called MIDWH-W2 which spans AD 1456 to AD 1624. Two precise felling dates in the springs of AD 1619 and AD 1625, together with three compatible felling-date ranges, indicate that construction is likely to have occurred in AD 1625, or soon after. The six year range between the two precise felling dates suggests that some stockpiled and/or windfall timber was used in the construction.

The average age of the source trees used in the construction is 73 years. Cross-matching against individual buildings and area reference chronologies is sufficiently high to indicate that the dated timbers probably came from local sources. Four of the samples dated show signs of management, the clearest sample shows a management practice such as pollarding or shredding (the lopping of branches usually for fodder) on a mean 15 year cycle.

ACKNOWLEDGEMENTS

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REFERENCES

Alcock, N W, Barley, M W, Dixon, P W, and Meeson, R A, 1996 *Recording timber-framed buildings: an illustrated glossary*, York (CBA).

Arnold, A J and Howard, R E, 2008 *Pridhamsleigh Manor and Farm, Staverton, Near Ashburton, Devon: Tree-ring analysis of timbers from the Dovecote.*, English Heritage, Research Department Report Series, **59/2008**

Baillie, M G L, 1982 *Tree-ring dating and archaeology*, London (Croom-Helm).

Baillie, M G L and Pilcher, J R, 1973 A simple cross-dating program for tree-ring research, *Tree-ring Bulletin*, **33**, 7-14.

Bridge, M C, 2008 *St Mary's Church, Cratfield, Suffolk: Tree-Ring Analysis of Timbers from the Bellframe and windlass*, English Heritage, Research Department Report Series, **30/2008**

Bridge, M C and Miles, D H, 2005 *Tree-ring analysis of oak timbers from Shrewsbury Castle, Shrewsbury, Shropshire* , English Heritage, Centre for Archaeol Rep, **57/2005**

Brunskill, R W, 2000 *Vernacular Architecture: an illustrated handbook*, London (Faber and Faber).

English Heritage, 2001 *Timber Dendrochronology of Roof Timbers at Lincoln Cathedral*, London (James & James (Science Publishers) Ltd).

Haddon-Reece, D, Miles, D H, and Munby, J T, 1990 List 38 - Tree-Ring Dates from the Ancient Monuments Laboratory, HBMC, *Vernacular Architect*, **21**, 46-50.

Harris, R, 1978 *Discovering timber-framed buildings*, Princess Risborough (Shire Publications).

Hillam, J, 1998 *Dendrochronology: Guidelines on producing and interpreting dendrochronological dates*, London (English Heritage).

Hillam, J, Morgan, R A, and Tyers, I, 1987 Sapwood estimates and the dating of short ring sequences, in *Applications of tree-ring studies: current research in dendrochronology and related areas* (ed R G W Ward), BAR Int Ser, **S333**, 165-85.

Howard, R E, Laxton, R R, and Litton, C D, 1998 *Tree-ring analysis from the timbers from St Andrew's Church, Owston, Leicestershire*, English Heritage, Anc Mon Lab Rep, **39/1998**

Laxton, R R and Litton, C D, 1988 *An East Midlands master tree-ring chronology and its use for dating vernacular buildings*, University of Nottingham, Dept of Classical and Archaeol Studies, Publication Monograph Ser, **3**

Miles, D H, 1996 *Tree-ring dating of 2 Milk Street, Shrewsbury, Shropshire*, English Heritage, Anc Mon Lab Rep, **25/96**

Miles, D H, 1997 The interpretation, presentation, and use of tree-ring dates, *Vernacular Architect*, **28**, 40-56.

Miles, D H, 2002 *The tree-ring dating of 8 Market Place, Shepton Mallet, Somerset*, English Heritage, Centre for Archaeol Rep, **4/2002**

Miles, D H, 2007 *HM Tower of London (TOL99 & TOL100) London Borough of Tower Hamlets - Tree-ring dating of the White Tower*, English Heritage, Centre for Archaeol Rep, **35/2007**

Miles, D H and Worthington, M J, 2006 *Merton College, Oxford, Oxfordshire. The tree-ring dating of the Fellows' Quadrangle*, English Heritage, Research Department Report Series, **80/2006**

Mills, C M, 1988 Dendrochronology: the long and short of it, in *Science and archaeology* (eds E A Slater, and J O Tate), Glasgow, BAR Int Ser, **196**, 549-65.

Moir, A K, 2003 *Dendrochronological analysis of oak timbers from Nyes Place, Newdigate, Surrey, England.*, Tree-Ring Services, Dendro Rep, **NEPN/39/03**

Moir, A K, 2004 *Dendrochronological analysis of oak timbers from Charlwood Place Farm, Charlwood, Surrey, England*, Tree-Ring Services, Dendro Rep, **CHPF/09/04**

Pearson, S, 1994 *The Medieval Houses of Kent, An Historical Analysis*, London (RCHME).

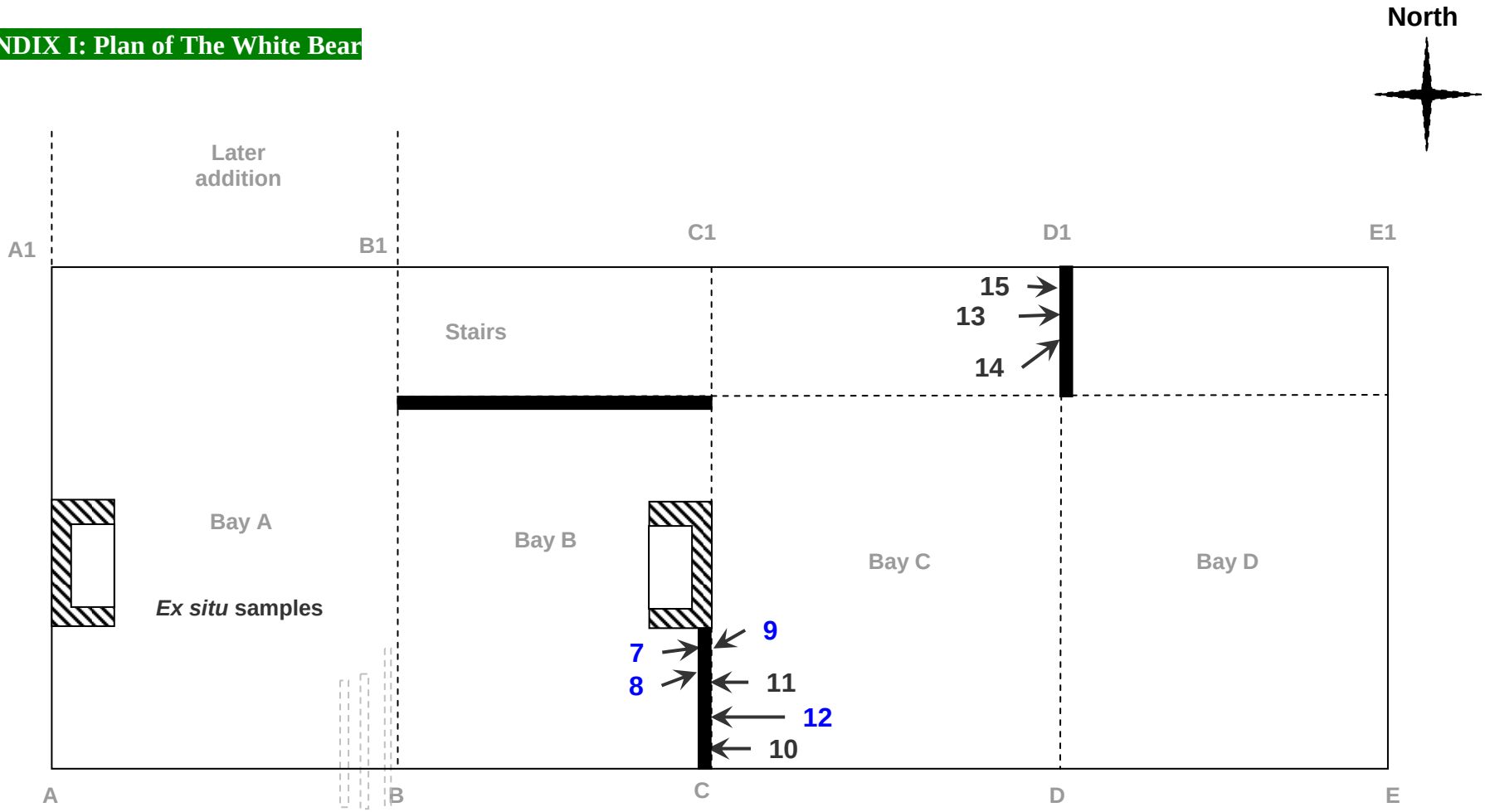
Rackham, O, 1990 *Trees and woodland in the British Landscape*, London (J M Dent & Sons Ltd).

Roberts, E, 2003 *Hampshire Houses 1250 - 1700: Their dating & Development*, (Hampshire County Council).

Tyers, I, 1998 *Tree-ring analysis and wood identification on timbers excavated on the Magistrates Court Site, Kingston upon Hull, East Yorkshire*, ARCUS Rep, **410**

Tyers, I, 1999 *Dendro for Windows Program Guide 2nd Edition*, ARCUS Rep, **500**

APPENDIX I: Plan of The White Bear



APPENDIX II: Raw ring-width data

Ring widths (0.01mm), starting with innermost measured ring

CWWB01

375	333	357	263	275	366	437	405	294	339
552	245	428	304	262	241	165	186	278	245
136	219	241	233	284	222	165	187	167	145
162	191	273	177	124	110	112	188	137	159
221	216	183	101	202	187	151	172	146	136
93	165	233	105	281	345	397	450	294	174
158	134	134	149	185	222	157	133	118	

CWWB02-S

136	214	147	206	201	76	77	120	116	154
185	287	284	305	319	390	198	148	183	207
208	252	111	104	113	159	201	198	307	310
216	216	164	284	221	178	161			

CWWB03

81	71	62	57	75	80	54	37	20	28
40	31	72	167	249	207	124	122	111	68
33	37	43	85	74	147	139	118	131	160
87	91	117	150	176	198	64	54	67	86
96	102	159	161	116	127	104	181	198	220
223									

CWWB04-S

478	257	292	258	248	222	226	265	193	203
131	183	130	143	117	103	79	122	96	181
146	153	115	138	102	110	108	130	223	183
82	77	86	104	100	125	249	200	127	133
123	193	159	122	151					

CWWB05

111	126	135	159	138	207	257	257	195	175
205	220	148	138	138	176	174	140	135	211
263	171	145	99	111	121	118	162	151	112
118	124	161	138	63	74	97	141	169	155
160	139	168	171	194	172	153	139	160	238
124	57	62	78	40	59	46	48	57	67
44	48	51	64	58	102	63	51	56	82
85									

CWWB06

150	279	229	356	324	220	391	183	161	182
160	218	225	226	276	379	289	441	343	298
294	348	181	166	164	153	213	222	321	218
266	298	217	222	199	289	258	253	147	173
233	142	175	194	172	191	287	302	255	198
205	236	237	222	80	70	62	82	85	95
120	128	105	115	132	119	108	112	121	125
60	35	53	52	75	102	125	127	93	159
93	108	122	120	120					

CWWB07-M

1177	745	355	295	463	702	435	382	328	340
467	552	557	635	429	468	349	309	381	400
542	522	482	354	373	311	403	272	225	169
232	229	311	308	333	301	190	135	174	205
235	213	114	112	201	216	119	206	222	296
207	284	168	173	199	136	56	57	66	91
93	81	119	126	97	153	108	101	113	84
76	71	48	46	43	84	75	97	78	141
92	164	149	177	114	88	52	61	70	81
146	153	205	168	126	141	133	144	146	

CWWB08-M

509	237	164	363	404	377	398	351	443	333
320	224	174	372	447	397	304	688	575	624
615	445	852	672	242	274	216	202	146	173
284	241	219	195	226	183	124	50	35	61
39	64	79	74	128	91	88	107	93	64
87	93	113	77	45	33	53	61	61	71
66	63	96	113	93	80	112	129		

CWWB09-M

289	236	307	292	102	104	147	152	143	114
150	359	322	430	351	464	386	193	87	92
95	146	120	194	139	195	126	181	255	247
260	122	75	127	242	205	110	152	167	190
151	294	268	333	295	234	162	92	65	94
90	114	101	100	187	196	156	268	217	226
100	55	34	51	59	98	106	67	89	69
76	89	95	86	100	127	133	167	97	52
92	41	40	58	56	79	78	75	76	85
104	123	109	124						

CWWB10-S

201	215	220	173	249	216	418	273	203	147
304	303	188	138	238	175	237	452	238	221
330	301	294	183	333	365	511	222	245	416
400	402	493	297	270					

CWWB11-S

213	226	191	120	138	73	144	124	161	204
211	238	166	171	107	69	59	100	123	83
125	106	60	49	40	78	79	48	99	94
61	36	43	50	63	55	66	77	51	75
68	74	96	105	115					

CWWB12-M

373	230	382	226	258	200	169	93	110	202
338	185	179	294	218	172	123	80	71	74
68	56	72	58	52	49	55	68	104	71
125	65	136	191	117	53	53	56	61	49
46	65	61	39	49	49	51	55	39	57
67	62	59	58	112	104	102	83	151	122
148	143	151	121	96	51	68	51	72	57
89	102	121	113	133	138	120	98	69	52
67	62	68	80	73	93	88	82	105	83
66	84	154	154	144	95	81	71	64	48
52	75	77	78	97	71	90	140	189	195
183	80	55	67	53	48	87	94	117	135
117	137								

CWWB13-S

279	183	254	231	88	87	44	27	27	31
98	124	151	358	233	279	211	281	156	88
96	107	132	159	212	227	244	236	213	144
222	330	458	538	453	473	662	493		

CWWB14-M

296	209	188	163	187	144	86	73	81	99
137	133	122	125	124	206	198	117	108	101
149	100	135	153	178	147	187	146	234	175
152	80	64	62	64	75	100	97	91	81
78	87	66	54	66	93	142	124	49	36
67	57	84	93	134	150	156	154	148	146
156	102	92	84	36	41	34	74	73	92
122	98	126	115	99	94	86	37	38	38
61	71	66	102	91	81	77	81	103	94
98	76	78	75	79	68	71	73	94	138
128	84	88	141						

APPENDIX III: Mean ring-width data

Title : The White Bear - Middlewich - Cheshire [MIDWH-W1]
Ring-width QUSP data of 51 years length
Undated; relative dates - 1 to 51
Unit of Measurement 0.01mm, 3 timbers raw data mean
Average ring width 146.27 Sensitivity 0.22

81	71	62	57	75	80	266	147	156	143
144	126	149	216	192	208	134	170	147	95
75	86	79	120	118	205	189	192	188	229
129	116	136	162	202	211	85	78	88	116
132	141	238	223	153	158	130	219	192	173
51	178								

Title : The White Bear - Middlewich - Cheshire [MIDWH-W2]
Ring-width QUSP data of 169 years length
Dated AD1456 to AD1624
Unit of Measurement 0.01mm, 6 timbers raw data mean
Average ring width 196.62 Sensitivity 0.21

AD1456						1177	745	355	295	463
	702	435	382	328	340	467	552	557	635	429
	468	349	309	381	400	542	447	356	368	299
	284	301	220	159	139	217	283	248	243	313
	259	181	129	181	170	205	191	90	96	135
AD1501	140	103	125	146	253	200	279	194	257	258
	148	65	67	72	99	87	107	208	154	106
	186	204	194	206	149	162	149	168	133	96
	180	198	196	153	310	257	325	305	245	328
	226	114	135	117	137	135	148	210	221	180
AD1551	235	211	194	145	129	87	100	92	118	147
	138	165	128	143	163	127	115	121	167	166
	156	103	110	142	95	93	94	96	106	131
	149	129	113	135	160	175	166	74	66	75
	92	100	112	124	128	136	134	154	145	130
AD1601	125	140	181	92	46	57	65	57	80	85
	87	75	113	68	78	86	92	89	102	63
	51	56	82	85						