Centre for Archaeology Report 38/2004

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ISSN 1473-9224

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Summary

A tree-ring dating programme was commissioned on timbers in the tower keep, the forebuilding, the porch, and the portcullis at Pendennis Castle, Cornwall, by English Heritage in AD 2001 and AD 2003. The tree-ring results indicate that timbers felled in AD 1540 and AD 1541 are present in the building.

Keywords

Dendrochronology
Standing Building

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Introduction

This document is a technical archive report on the tree-ring analysis of oak timbers from the tower keep, forebuilding, porch, and portcullis of Pendennis Castle nr Falmouth, Cornwall (NGR SW 825 320). 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.

Pendennis Castle is a Scheduled Ancient Monument that lies on a headland between Falmouth Bay and the River Fal (Figs 1 and 2). The dominant structure on the headland is the castle tower, sometimes called the keep since it has the appearance of a medieval castle keep. Its initial function was as a gun platform for the defence of the Fal estuary. Pendennis Castle and St Mawes Castle on the opposite headland are members of a series of coastal artillery castles built along the south coast of England. The construction of these began to be considered in AD 1539, after the threat of invasion in AD 1538. The building accounts for Pendennis Castle commenced on 4 October AD 1540 (Colvin 1982, 596).

The following description is based on that of Nick Molyneux (pers comm). The tower is circular in plan and of two storeys (Figs 3 and 4), with a basement, and a gun platform on the roof. The ground floor has circular gun ports, the first floor has arched and splayed gun ports, and the roof has a parapet with gun embrasures and the curved top characteristic of many of the coastal forts. The basement is cut into the bedrock and contains a kitchen. Internally the plan is octagonal and a series of large beams span the internal space forming the ceilings of all the floors. The timber structure of the basement ceiling was replaced in AD 1981/2, and the first-floor ceiling and roof was reconstructed in a mixture of oak and pine probably in the early-nineteenth century, although some of the oak may be re-used from the original timbers.

The tower is surrounded by a multiangular outer wall (or chemise) defining the inner edge of a dry moat (Fig 3). The chemise is not dateable precisely, although it was in place by the time of the first drawings of the castle in the AD 1540s. When it was constructed it would have made the ground floor of the castle unusable as a gun deck, because firing guns from there would have killed those on the chemise. Plans of the AD 1620s show the ground floor divided for domestic use. It seems a reasonable hypothesis that the chemise belongs to an initial (if slightly secondary) construction of the castle.

The two-storey forebuilding (sometimes called the Governor's Lodging) is attached to the north side of the tower (Figs 3 and 4), and is straight jointed against it. It consists of

a main block with an entrance porch to the west side. The main door is defended by a timber portcullis (Fig 5). Above the door there is an impressive carved Royal arms. It is so close in style to the more elaborate decoration of St Mawes Castle as to be from the same hand (Colvin 1982, 598). The large lintel which projects above the arched doorway and supports the arms is carved to carry around the corner to the main block and demonstrates that the forebuilding is all of one build.

The main block included domestic accommodation from the outset, with a large fireplace at ground- and first-floor level in the room nearest to the keep. On the ground and first floors there are gun ports to the north elevation overlooking the approach to the bridge (and the now ruinous guardhouse). Further evidence that the forebuilding is secondary is provided by the hood moulding over the entrance to the tower which has been shaved off. The construction of the forebuilding also blocked one of the first-floor gun ports.

The physical evidence that the gatehouse is secondary cannot resolve the length of time involved. Colvin (1982, 598) cites three arguments in favour of the forebuilding being an early addition. Firstly, on the grounds that it is very unlikely to have been constructed by Queen Elizabeth due to her financial constraints. Secondly, on the similarity of the coat of arms to the work at St Mawes of the AD 1540s. Thirdly, that there is some documentary evidence for work at Pendennis in *c* AD 1550.

Tree-ring analysis of timbers in both the tower keep and the forebuilding was commissioned by Nick Molyneux, the local English Heritage Historic Buildings Inspector, in preparation for a new visitors guide book.

Methodology

The general methodology and working practises used at the Sheffield Dendrochronology Laboratory are described in English Heritage (1998). The methodology used for this building was as follows.

The tower keep of the castle was visited in company with Nick Molyneux, the local English Heritage Historic Buildings Inspector, and an assessment of the dendrochronological potential of the various parts of the tower keep was undertaken. This assessment aimed to identify whether oak timbers with sufficient numbers of rings for analysis existed in this part of the structure. This assessment identified that several parts of this building contained suitable material. These timbers were sampled during this visit. These samples were analysed and, following the interim results, the sampling brief was extended and a subsequent visit was made, again with the Inspector, to assess the various structures in the forebuilding.

A further visit was made for the dendrochronological sampling of the suitable material in this area. In both instances the sampling programme aimed to obtain samples from as broad a range of timbers, in terms of structural element types, scantling sizes, carpentry features, and surface condition as was possible with respect to their suitability for analysis, their safe access, and within the terms of the request and the relevant Class VI Scheduled Monument Consents.

On both occasions the most promising timbers were sampled using a 15mm diameter corer attached to an electric drill. The cores were taken as closely as possible along the radius of the timbers so that the maximum number of rings could be obtained for subsequent analysis. The core holes were filled with oak plugs. The ring sequences in the cores were revealed by sanding.

The complete sequences of growth rings in the cores were measured to an accuracy of 0.01mm using a micro-computer based travelling stage (Tyers 1999). The ring sequences were plotted onto semi-log graph paper to enable visual comparisons to be made between sequences. In addition a cross-correlation algorithm (Baillie and Pilcher 1973) was employed to search for positions where the ring sequences were highly correlated. These positions were checked visually using the graphs and, where these were satisfactory, new mean sequences were constructed from the synchronised sequences. The *t*-values reported 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, although this is with the proviso that high *t*-values at the same relative or absolute position must be obtained from a range of independent sequences, and that these positions are supported by satisfactory visual matching.

All of the measured sequences from this assemblage were compared with each other and any found to cross-match were combined to form a site master curve. These, and any remaining unmatched ring sequences, were tested against a range of reference chronologies, using the same matching criteria: high *t*-values, replicated values against a range of chronologies at the same position, and satisfactory visual matching. Where such positions are found these provide calendar dates for the ring-sequence.

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 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 throughout this report are a minimum of 10 and maximum of 46 annual rings, where these figures indicate the 95% confidence limits of the range (Tyers 1998). These figures are applicable to oaks from England and Wales. Alternatively, if bark-edge survives, then a felling date can be directly utilised from the date of the last surviving ring. 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 the re-use of timbers, seasoning, and the repairs of structures before the dendrochronological dates given here can be reliably interpreted as reflecting the construction date of phases within the structure.

Results

Six timbers were selected for sampling from the ground-floor gun deck ceiling of the tower keep, and four from the first-floor gun deck ceiling. These samples were numbered **1-10** (Table 1a; Figs 3 and 4). Seventeen timbers were selected for sampling from various parts of the forebuilding, porch, and portcullis. The samples were numbered **11-27** (Table 1b; Figs 3-5).

All of the sampled timbers are oak (*Quercus* spp.). Three of the samples were found to be unsuitable for analysis since they contained series of irresolvable bands of narrow rings. The tree-ring series from the remaining 24 sampled timbers were measured and the resultant series were then compared with each other. Seventeen were found to match together to form an internally consistent group (Table 2). A site mean chronology was calculated, named PENDENNIS. This site mean was then compared with dated reference chronologies from throughout the British Isles and northern Europe. A single well correlated position was identified for this sequence. Table 3 shows example correlations at its identified dating position against independent reference chronologies. Table 1 provides the chronological dates identified for each component sample by this process and their interpretation. Figure 6 shows the chronological position identified for each component sample. Appendix 1 lists the individual sample series. The seven unmatched samples were compared to the reference chronologies but they are undated by the analysis reported here.

Interpretation and discussion

The 184-year chronology PENDENNIS is dated AD 1358 to AD 1541 inclusive. It was created from 17 of the sampled timbers. Two of the datable samples are complete to the original bark surface, a further sample retains some sapwood, and another seven are complete to the heartwood/sapwood boundary.

Four of the dated samples are from the ceiling of the ground-floor gun deck of the tower keep. One of these dated timbers is complete to the original bark surface and this was felled within the late spring or summer of AD 1540. The three other dated samples from this ceiling either retain some sapwood, or are complete to the heartwood/sapwood boundary, and all appear likely to be contemporaneous with the AD 1540 felling date (Fig 6; Table 1a). The unmatched samples are from joists, no dating has been identified for these components of the ceiling.

Likewise none of the samples from the ceiling of the first floor have proven datable and the presumption that they include timbers of AD 1540 date cannot be proven (Table 1a).

Eleven of the dated timbers are from the three components of the entrance porch into the forebuilding. Five from the first-floor ceiling, four from the portcullis, and two from the ceiling of the ground-floor entrance itself. These two ceilings create a winding room for the portcullis directly over the entrance. One of these dated timbers is complete to the original bark surface and this was felled within the summer of AD 1541. Several other dated samples from these areas are complete to the heartwood/sapwood boundary, and all appear likely to be contemporaneous with the AD 1541 felling date (Fig 6; Table 1b). The unmatched samples are mostly further samples from the joists of the ground-floor ceiling which form a continuously numbered series along with the dated examples. There seems little doubt they, and the undated timbers in the portcullis, are also contemporaneous.

The final two datable samples are both the sole examples recoverable from other key parts of the forebuilding structure. Sample **26** derives from a ground floor ceiling beam that runs across the front of the original entrance to the round tower, whilst sample **27** derives from an original, but reset, timber in the roof of the forebuilding tower. Both are complete to the heartwood/sapwood boundary, and both appear likely to be contemporaneous with the felling date obtained from the entrance porch (Fig 6; Table 1b).

It is impossible to distinguish which, if any, of the timbers without bark-edge are precisely contemporaneous with either the AD 1540 or AD 1541 felling dates. Indeed since there are only two of these it is not clear that they are representative of the particular area of the structure from which they derive. It is therefore possible that these two felling dates are indicating the broad dating of a structure whose design changed during an extended construction period using a stockpile of material felled across this period. However there is clear structural evidence that the area producing the latest felling date is the later structure. This may be co-incidence but it is possible that we have successfully dated the original construction of the tower keep to AD 1540, and the

near contemporary modifications to it, involving the addition of the chemise, the forebuilding, and the entrance porch, to AD 1541.

The portcullis is revealed to be broadly contemporaneous, in all probability precisely so. This may make it the only portcullis of the Henry VIII period still *in situ* in England. The timbers are demonstrably original and the diamond headed rove nails, like those seen on medieval church doors and medieval clinker vessels, are highly likely to be original. Perhaps the likelihood that it never saw any action, and that its function was probably symbolic following the remodelling of the castle, has aided its survival.

Conclusion

Assuming the timbers were felled for immediate usage, which was normal practice in this period (Charles and Charles 1995), then the original tower keep may date from the summer of AD 1540, or shortly thereafter, whilst the forebuilding, the portcullis, and the entrance porch may date from the summer of AD 1541 or shortly thereafter.

The analysis of timbers from Pendennis Castle along with timbers from several other buildings in Cornwall have recently provided a series of dated chronologies each covering parts of the fifteenth and/or sixteenth centuries. This group of buildings thus provides some indication that dendrochronology may be successfully applied to Cornish buildings. This has hitherto been in some doubt.

Acknowledgements

The sampling and analysis programme was funded by English Heritage. Nick Molyneux and Peter Marshall both from English Heritage put together the request documentation. Nick Molyneux provided the description of the sampled areas. Cathy Groves provided useful discussion of the results and the report. Callie Saxtie and the site team at Pendennis provided access to the building and practical assistance.

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Figure 1 Location of Falmouth, Cornwall, within England and Wales.

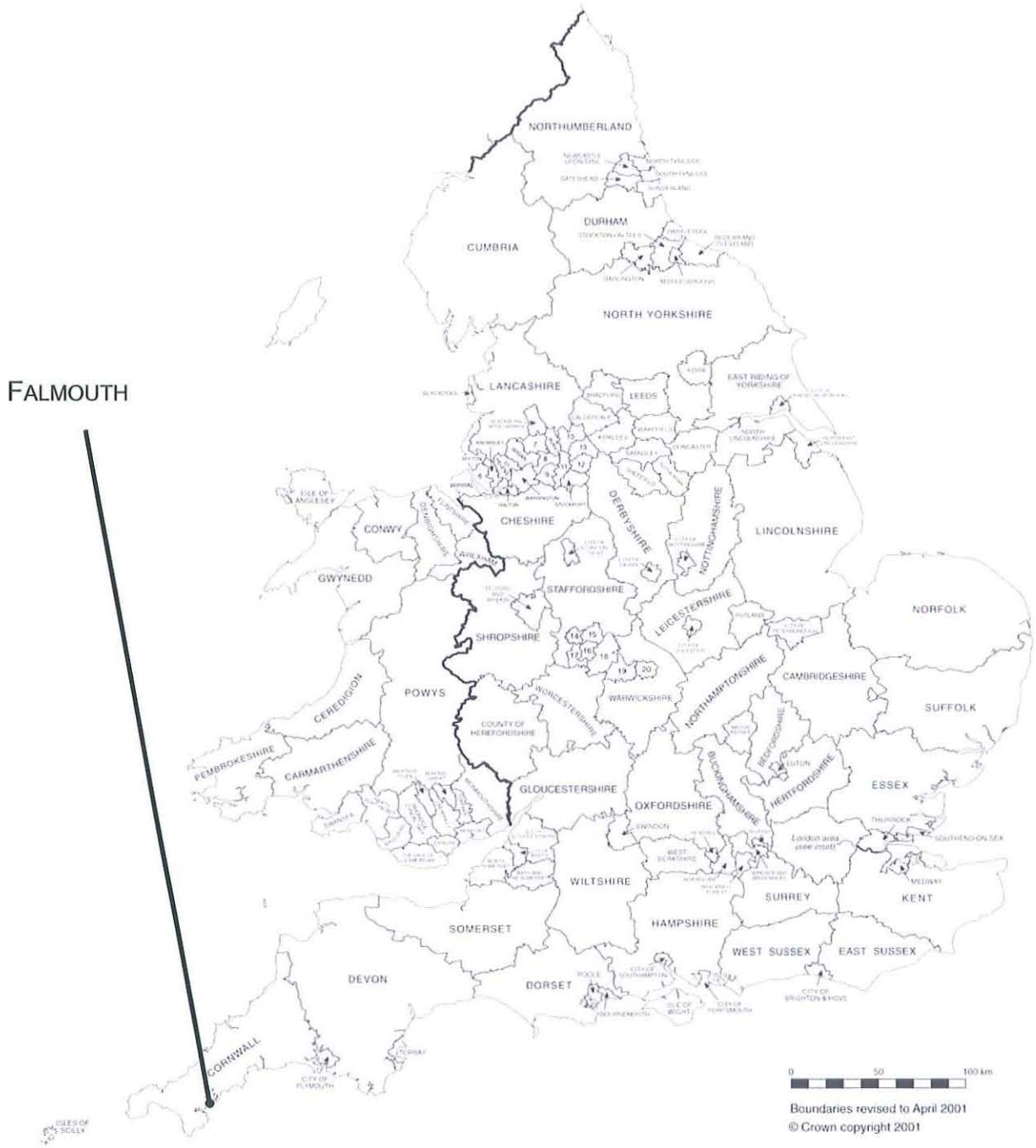


Figure 2 Location of Pendennis Castle, nr Falmouth, Cornwall

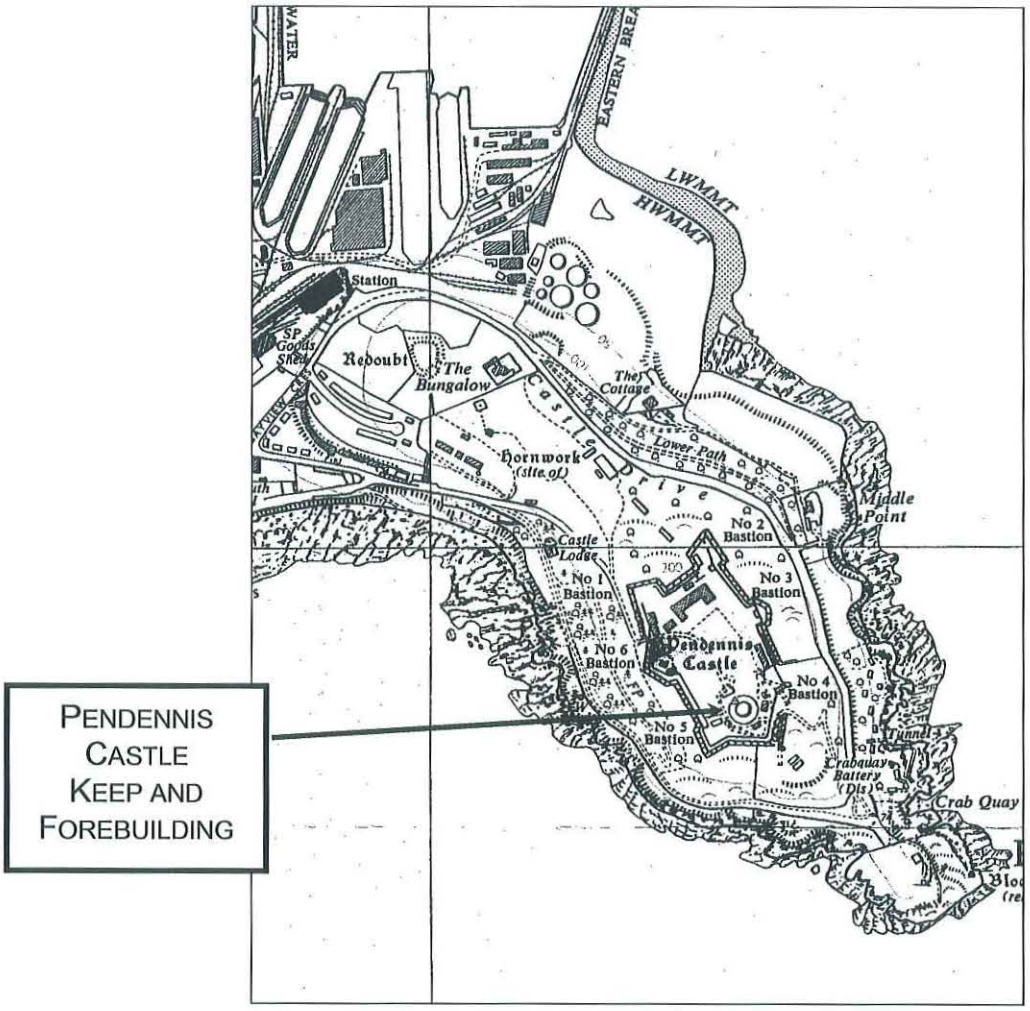


Figure 3 Ground floor of Pendennis Castle, nr Falmouth, Cornwall showing the keep, forebuilding, porch, and part of the chemise wall. The labelled arrows indicate the approximate locations of the sampled timbers (plan based upon a Ministry of Works diagram *c* 1932 supplied by English Heritage)

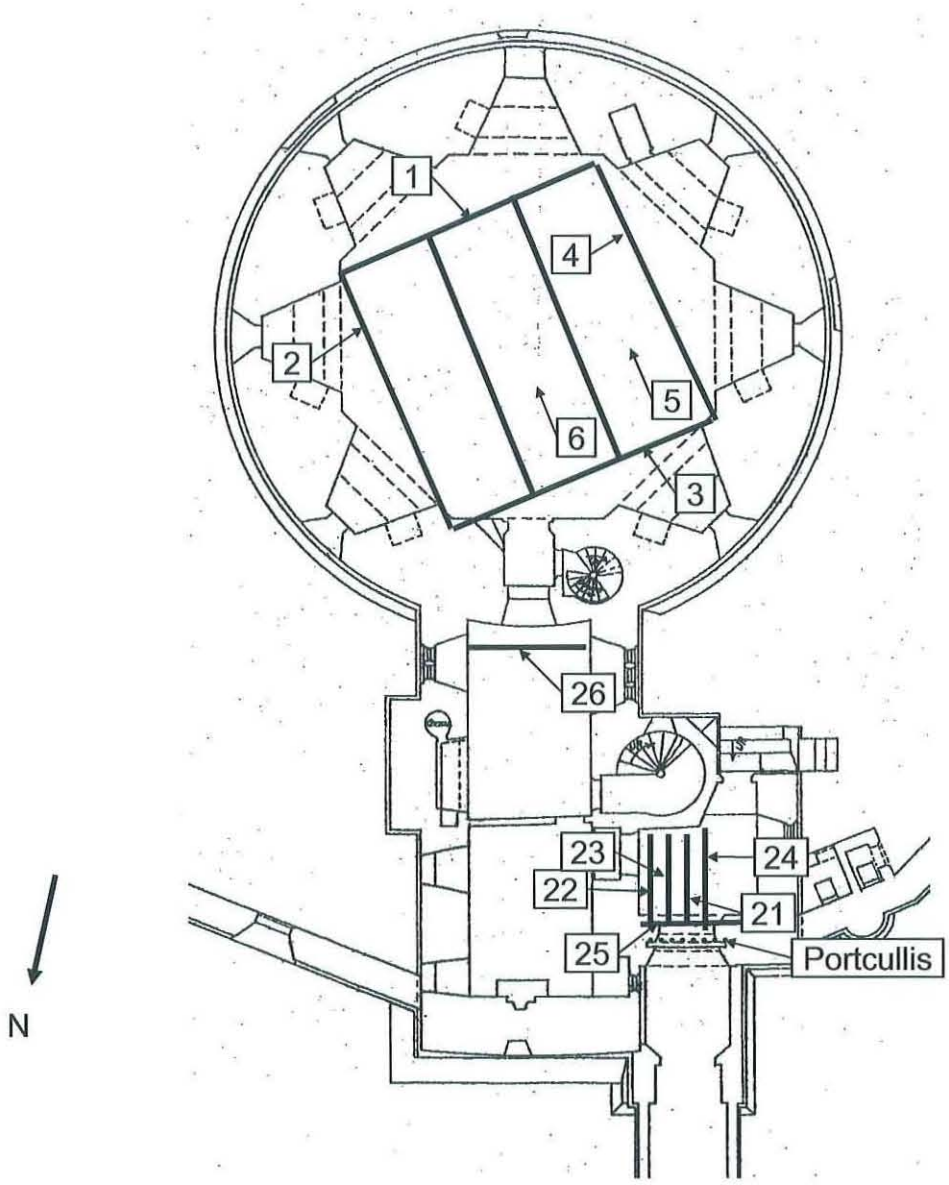


Figure 4 First floor of Pendennis Castle, nr Falmouth, Cornwall showing the keep, forebuilding and porch. The labelled arrows indicate the approximate locations of the sampled timbers (plan based upon a Ministry of Works diagram *c* 1932 supplied by English Heritage), NB sample **27** is from the top of the tower a further floor above

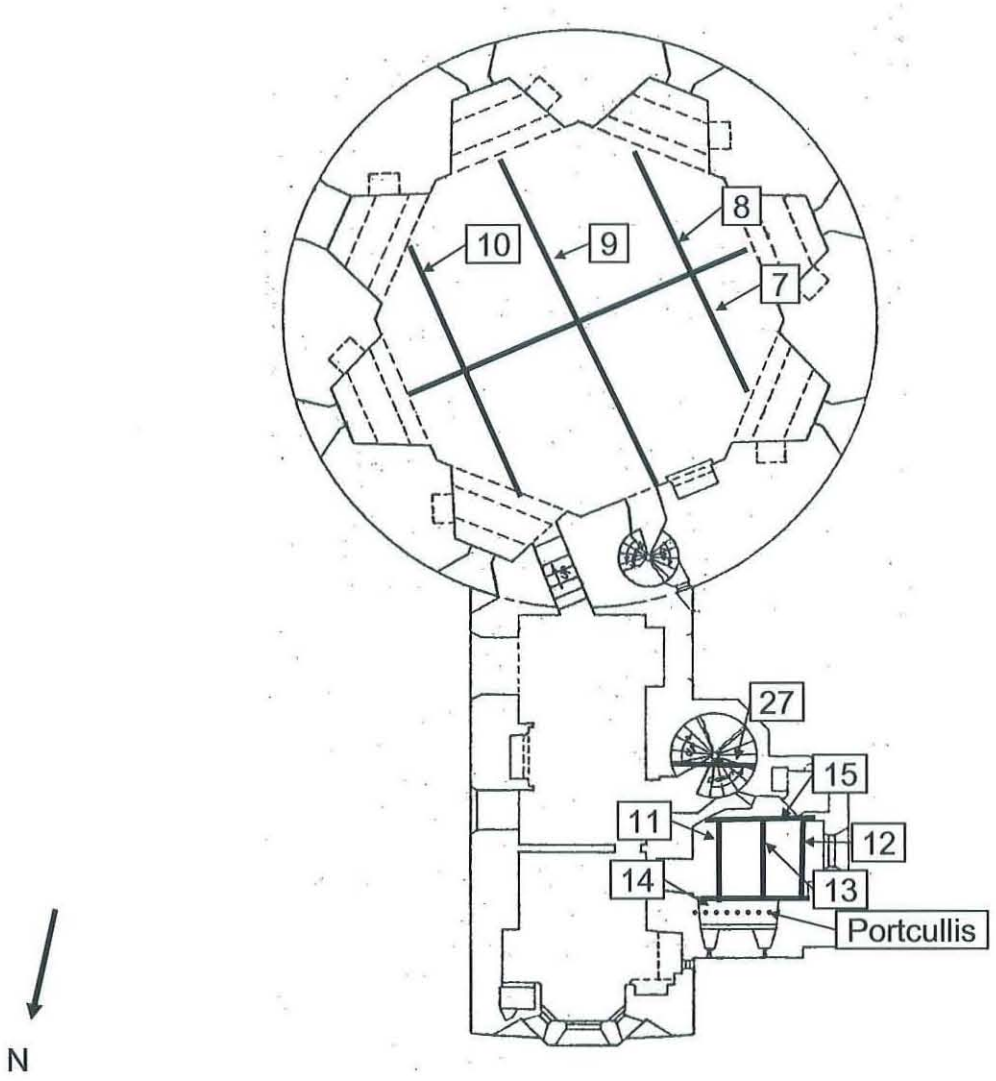


Figure 5 A 1928 photograph of the portcullis in its raised position, viewed from inside the first-floor chamber of the porch. The labelled arrows indicate the sampled timbers from this object. Photograph © Crown copyright, NMR (AL851/10/2), supplied by English Heritage

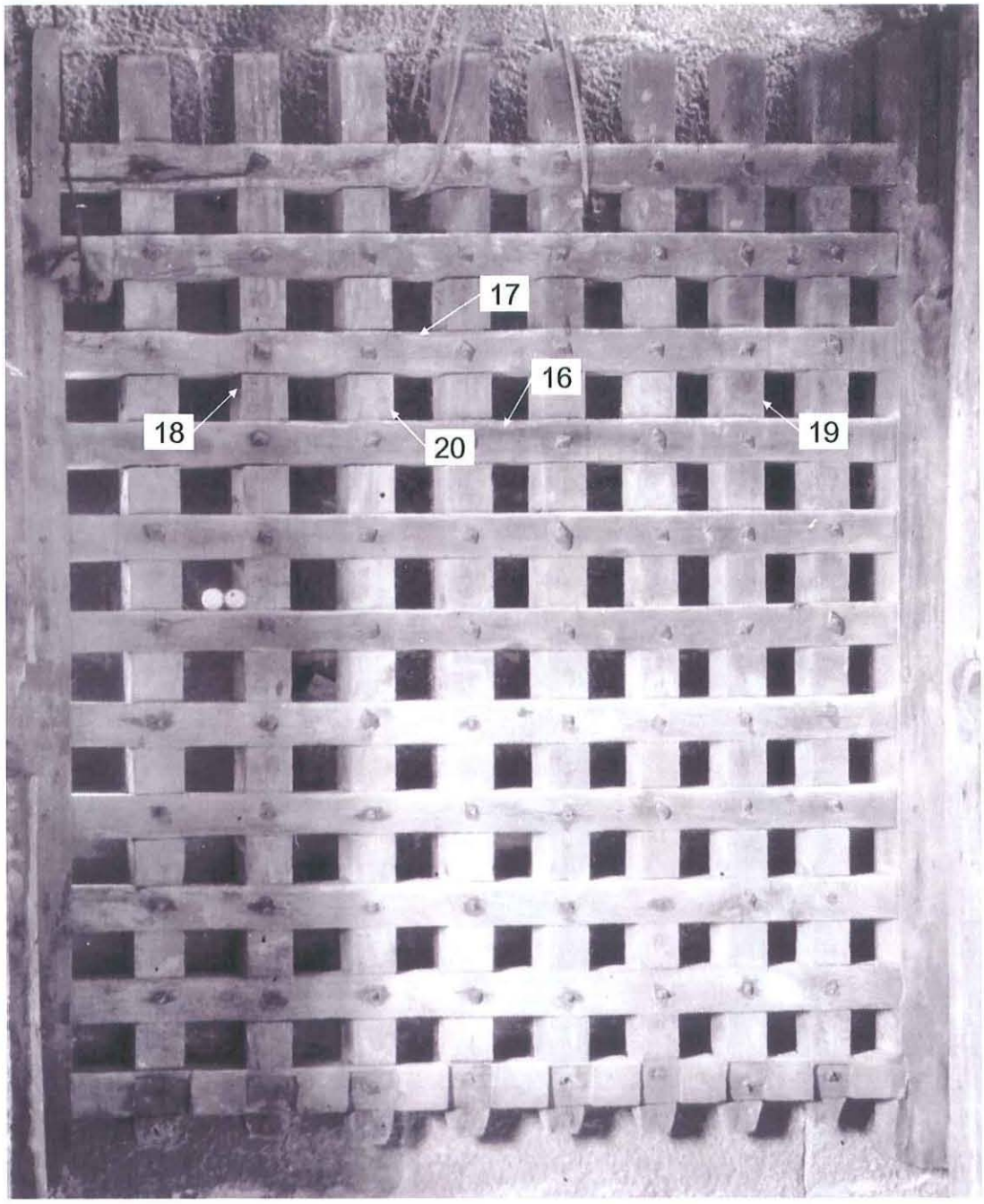
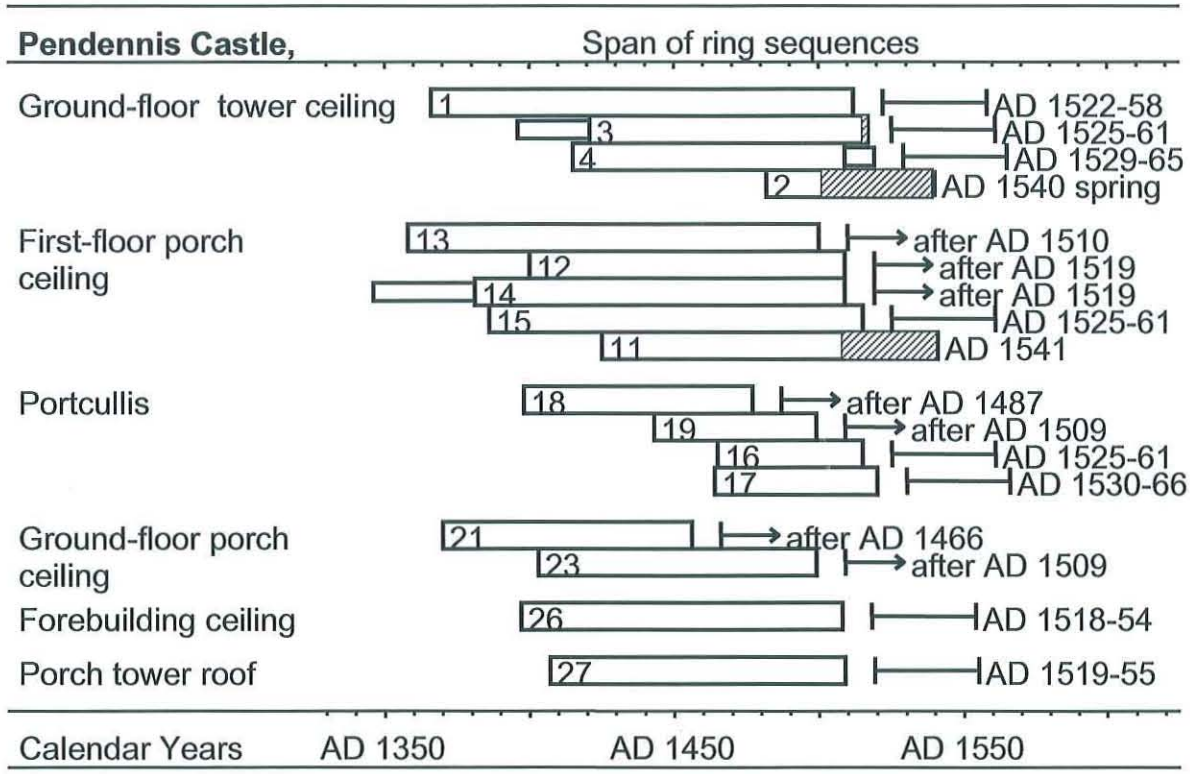


Figure 6 Bar diagram showing the chronological positions of the dated timbers from Pendennis Castle, nr Falmouth, Cornwall. The estimated felling period for each sequence is also shown



KEY for figure 6

Table 1a List of samples from the ground- and first-floor gun deck ceilings of the tower keep at Pendennis Castle, nr Falmouth, Cornwall

Core No	Origin of core	Cross-section size (mm)	Total rings	Sapwood rings	ARW (mm/year)	Date of sequence	Felling period
1	Lower ceiling beam	380 x 380	147	H/S	2.01	AD 1366-AD 1512	AD 1522-58
2	Lower ceiling beam	380 x 350	*46*+58	38+½Bs	1.70	AD 1482-AD 1539	AD 1540 spring
3	Lower ceiling beam	400 x 370	*25*+97	2	2.40	AD 1421-AD 1517	AD 1525-61
4	Lower ceiling beam	350 x 330	95+*10*	H/S	1.67	AD 1415-AD 1509	AD 1529-65
5	Lower ceiling joist	170 x 120	93	36+½Bs	1.62	undated	-
6	Lower ceiling joist	170 x 120	61	-	1.37	undated	-
7	Upper ceiling beam	280 x 140	63	20+½Bs	2.62	undated	-
8	Upper ceiling beam	260 x 150	58	20+½Bs	2.76	undated	-
9	Upper ceiling beam	300 x 260	53	13+½Bs	1.30	undated	-
10	Upper ceiling beam	260 x 140	-	-	-	unmeasured	-

KEY for Table 1a See Figs 3 and 4 for sampling locations. Total rings = all measured rings, values in italics indicate unmeasurable or disconnected sections of the samples. Sapwood rings: H/S heartwood/sapwood boundary, +½Bs bark spring felled in following year, ARW = average ring width of the measured rings

Table 1b List of samples from the forebuilding, porch, and portcullis at Pendennis Castle, nr Falmouth, Cornwall

Core No	Origin of core	Cross-section size (mm)	Total rings	Sapwood rings	ARW (mm/year)	Date of sequence	Felling period
11	Upper porch ceiling beam	160 x 150	117	33+Bs	1.44	AD 1425-AD 1541	AD 1541 summer
12	Upper porch ceiling beam	180 x 140	110	-	1.54	AD 1400-AD 1509	after AD 1519
13	Upper porch ceiling beam	180 x 140	143	-	1.50	AD 1358-AD 1500	after AD 1510
14	Upper porch ceiling beam	300 x 290	*35*+129	-	1.57	AD 1381-AD 1509	after AD 1519
15	Upper porch ceiling beam	300 x 290	130	H/S	1.72	AD 1386-AD 1515	AD 1525-61
16	Portcullis horizontal	100 x 70	51	H/S	1.91	AD 1465-AD 1515	AD 1525-61
17	Portcullis horizontal	90 x 75	57	H/S	1.67	AD 1464-AD 1520	AD 1530-66
18	Portcullis vertical	95 x 70	80	-	1.24	AD 1398-AD 1477	after AD 1487
19	Portcullis vertical	95 x 70	57	-	1.77	AD 1443-AD 1499	after AD 1509
20	Portcullis vertical	100 x 80	54	-	1.98	undated	-
21	Lower porch ceiling joist	270 x 90	87	-	3.00	AD 1370-AD 1456	after AD 1466
22	Lower porch ceiling joist	240 x 90	89	H/S	1.61	undated	-
23	Lower porch ceiling joist	250 x 90	97	-	2.47	AD 1403-AD 1499	after AD 1509
24	Lower porch ceiling joist	250 x 85	-	-	-	unmeasured	-
25	Lower porch ceiling plate	260 x 260	-	-	-	unmeasured	-
26	Forebuilding ceiling beam	260 x ?	112	H/S	1.89	AD 1397-AD 1508	AD 1518-54
27	Porch tower roof	230 x 170	103	H/S	2.03	AD 1407-AD 1509	AD 1519-55

KEY for Table 1b See Figs 3-5 for sample locations. The timber from which sample **26** was taken is embedded in a ceiling and its cross-section dimensions could not be measured. Total rings = all measured rings, values in italics indicate unmeasurable or disconnected sections of the samples. Sapwood rings: H/S heartwood/sapwood boundary, Bs bark summer felled, ARW = average ring width of the measured rings

Table 2

t-value matrix for the timbers forming the chronology PENDENNIS, KEY - = *t*-value less than 3.0, \ = overlap less than 15 years

	2	3	4	11	12	13	14	15	16	17	18	19	21	23	26	27
1	5.27	5.11	6.10	4.42	6.04	7.11	5.76	5.93	5.10	5.16	3.27	-	4.93	-	4.05	-
2		3.88	3.70	3.58	5.80	-	-	4.25	3.42	3.56	\	-	\	-	-	-
3			-	-	3.13	3.17	-	-	-	3.33	-	-	-	-	-	3.34
4				3.97	5.63	4.74	5.80	4.18	3.28	-	-	-	3.85	3.65	-	4.57
11					9.39	6.67	5.22	3.26	5.15	3.00	3.14	3.71	-	3.65	-	4.14
12						8.62	6.33	3.96	4.79	3.47	-	4.10	7.20	5.08	3.18	3.31
13							6.28	6.18	6.27	5.61	-	-	6.64	4.78	5.41	3.96
14								4.58	6.13	3.97	-	4.03	4.45	6.01	4.16	-
15									4.08	3.89	3.72	3.71	4.51	-	3.92	3.57
16										4.37	\	-	\	-	3.40	-
17											\	-	\	-	3.89	-
18												3.63	-	-	-	-
19													\	-	-	3.30
21														7.83	5.73	-
23															5.16	-
26																-

Table 3

Dating the mean sequence PENDENNIS, AD 1358-1541 inclusive. Example *t*-values with independent reference chronologies

Reference chronology	*t*-value
Cornwall, Cotehele House nr Calstock (author in prep)	7.19
Cornwall, Godolphin House (Groves in prep)	8.00
Cornwall, Roscarrock nr St Endellion (Tyers 2004a)	8.59
Devon, Crediton Holy Cross church (Tyers 2004b)	8.74
Devon, Exeter Bowhill (Tyers and Groves 1999)	7.69
Devon, Prowse Farm Barn (Tyers *et al* 1997)	8.27
Gloucestershire, Gloucester Mercers Hall (Howard *et al* 1996)	8.73
Herefordshire, Hereford 14 Church St (Tyers 1996)	7.69
Herefordshire, Widemarsh St Hereford Farmers Club (Tyers 1996)	8.25
Welsh Border (Siebenlist-Kerner 1978)	7.86

Appendix 1 Ring width data for measured samples from Pendennis Castle, nr Falmouth, Cornwall, 100 = 1mm

pen01

148	140	137	332	221	177	205	302	298	180
199	216	226	256	271	186	233	277	299	227
274	270	227	307	210	302	263	284	225	408
364	327	230	363	296	298	263	308	362	371
422	334	379	269	252	201	232	305	294	279
238	190	247	158	281	208	170	273	376	262
170	183	319	328	331	258	330	280	289	307
175	223	276	245	208	192	100	121	137	172
162	194	145	150	130	128	159	155	127	110
136	160	160	91	105	69	104	101	67	131
124	166	146	127	147	148	111	124	100	128
166	93	139	151	142	130	117	134	151	152
135	129	123	106	132	145	101	171	137	129
234	151	89	109	122	106	126	134	154	135
134	153	187	145	115	163	136			

pen02

232	237	226	263	209	262	255	216	230	248
195	211	198	175	234	181	160	168	209	166
177	174	187	167	162	146	150	160	103	155
177	171	160	144	122	127	118	121	119	147
148	143	133	158	148	139	141	103	132	169
109	125	140	148	159	181	156	148		

pen03

562	261	465	438	306	370	214	301	281	306
314	350	279	284	285	253	305	379	386	268
218	146	333	291	293	163	345	356	291	180
174	186	225	207	212	211	189	194	153	191
173	216	231	210	368	305	320	372	229	377
294	242	223	279	209	311	190	188	202	202
285	191	278	260	215	179	274	257	182	188
161	149	253	140	144	277	204	162	209	151
139	203	251	268	286	200	163	154	228	111
136	125	117	114	113	97	93			

pen04

411	178	177	385	215	397	270	254	407	382
307	245	202	351	297	260	291	230	235	241
363	233	244	186	166	189	203	164	177	179
192	219	158	143	161	150	126	140	123	122
112	110	92	90	81	82	101	86	104	72
86	84	122	128	106	122	123	102	144	139
193	208	112	161	159	139	220	163	169	139
107	105	101	99	56	88	117	119	113	163
122	132	108	54	68	109	92	102	122	124
137	131	103	153	156					

pen05

124	88	86	130	134	195	123	231	172	248
294	334	254	182	101	159	232	192	200	336
284	407	310	265	189	193	233	167	248	236
189	215	200	167	230	142	147	125	131	136
134	115	74	87	76	75	87	87	121	141
85	78	77	70	89	85	94	136	106	79
104	122	93	87	67	68	62	65	91	93
121	232	221	178	224	198	198	219	150	178
146	148	132	151	202	209	234	199	262	257
171	111	114							

pen06

115	88	109	173	139	142	201	167	201	135
139	162	136	126	140	144	124	176	171	209
179	138	199	102	101	116	114	194	175	133
117	111	94	199	138	120	152	114	92	89
91	96	98	87	121	161	101	141	164	184
210	163	176	104	110	131	92	177	158	64
84									

pen07

444	541	267	391	402	344	432	256	384	513
354	442	355	369	348	482	393	335	367	279
309	322	387	352	323	308	423	334	301	233
212	251	218	166	209	234	293	171	140	128
100	169	217	177	161	196	187	185	130	126
109	84	97	106	121	167	134	168	189	137
154	165	221							

pen08

419	501	318	520	560	391	569	395	476	433
417	422	353	377	239	280	291	277	304	299
329	493	429	384	379	262	243	252	213	213
265	264	205	178	242	252	193	217	285	178
172	195	210	168	175	118	95	106	118	124
167	142	155	138	148	148	138	169		

pen09

217	223	221	144	124	174	174	193	163	159
158	153	197	189	205	196	195	137	145	120
136	114	94	107	102	162	102	124	117	124
88	94	87	87	79	82	98	74	89	118
96	129	132	127	88	86	145	93	109	75
83	68	83							

pen11

243	292	150	156	225	201	307	257	212	191
303	199	215	149	111	167	152	82	157	128
99	88	118	85	121	93	130	151	115	157
125	127	127	167	116	111	120	152	169	122
172	180	249	176	89	108	85	148	144	147
172	169	132	118	83	115	113	89	139	166
194	131	133	121	84	101	127	108	110	188
163	262	168	115	138	164	145	218	165	300
222	161	167	141	110	91	156	96	135	102
85	96	74	61	50	45	66	63	67	65
81	106	97	123	108	82	172	137	165	122
183	91	233	172	247	227	94			

pen12

200	236	152	250	238	254	214	190	233	128
194	135	188	199	189	130	155	154	138	103
166	154	109	218	210	213	187	97	121	114
84	163	178	164	122	212	148	204	155	123
145	138	102	153	124	128	152	134	112	114
100	112	106	125	132	133	126	126	152	129
112	113	148	134	102	146	153	174	162	101
145	113	189	143	125	158	172	100	162	94
142	171	130	162	193	214	152	166	175	116
208	158	105	108	164	157	288	145	103	177
219	128	131	130	212	206	182	144	150	116

pen13

155	136	128	131	104	113	122	106	106	143
116	159	176	108	129	104	107	131	181	182
126	166	113	97	93	118	205	156	198	195
206	209	140	205	118	157	109	180	154	155
151	174	206	212	162	246	220	344	297	219
343	278	237	188	215	226	290	202	236	177
221	181	276	214	125	224	278	237	207	104
139	168	154	225	209	175	140	188	158	158
132	118	124	163	92	124	98	114	111	106
132	99	58	84	97	83	90	61	118	119
136	103	103	108	118	109	88	143	168	189
193	128	148	106	123	134	125	155	168	98
96	97	106	106	103	95	110	113	73	88
95	82	137	100	77	87	192	139	235	154
119	90	101							

pen14

63	62	55	64	70	82	93	110	96	61
103	108	118	128	126	141	115	148	183	113
140	121	151	116	102	104	125	191	154	111
147	223	230	244	228	182	186	160	100	225
181	112	201	185	154	184	119	178	162	137
154	127	136	125	155	124	180	148	110	145
156	109	172	165	192	231	157	87	141	88
103	147	174	183	165	173	179	183	180	145
164	166	203	135	208	197	243	254	195	245
152	174	131	215	264	224	131	109	173	220
213	196	186	252	230	249	199	265	155	197
164	130	129	182	148	182	148	90	116	112
109	145	179	186	152	154	187	161	171	

pen15

306	248	149	214	127	313	104	94	92	203
222	181	160	188	221	223	200	274	245	241
240	186	210	209	187	111	154	205	247	190
182	159	144	94	166	178	122	230	286	213
326	210	218	265	228	192	153	153	238	318
273	221	172	143	153	202	110	130	228	199
182	136	160	126	115	153	181	157	252	143
179	146	62	66	104	45	51	90	71	149
188	247	264	169	172	124	95	82	72	135
107	82	51	51	87	96	82	79	127	169
184	233	228	191	186	261	145	283	272	189
252	187	92	90	155	148	156	166	199	192
131	137	129	157	112	100	187	175	286	233

pen16

208	270	220	214	170	195	80	116	123	132
179	226	91	72	132	149	199	150	151	271
269	260	217	205	158	256	267	173	148	277
145	376	161	88	97	125	124	121	144	392
245	303	363	258	149	84	139	114	195	261
276									

pen17

99	123	165	186	198	161	154	106	104	138
131	231	170	124	150	177	159	180	165	252
254	252	272	261	265	204	251	157	114	144
212	134	305	195	142	135	105	117	154	120
219	152	146	157	180	226	147	167	189	163
187	132	94	106	80	113	86			

pen18

195	243	180	148	182	169	195	153	118	121
123	116	94	71	78	91	120	126	113	112
103	70	54	69	82	121	164	142	106	128
158	155	103	112	113	114	105	145	165	141
131	107	182	148	111	116	172	116	123	99
97	120	111	150	137	133	126	125	112	138
139	105	135	92	93	91	79	96	124	108
143	121	180	116	128	99	97	131	122	92

pen19

220	179	229	257	176	188	328	208	175	225
185	220	187	166	172	177	125	134	109	138
159	107	171	284	384	237	142	181	103	111
75	79	208	196	237	175	140	189	180	133
80	121	200	224	226	190	179	254	205	154
149	180	133	157	99	99	135			

pen20

310	164	130	146	134	112	56	69	109	76
79	59	80	71	120	74	64	57	61	53
67	98	78	115	135	133	162	168	245	429
230	397	245	383	209	358	266	330	299	349
210	191	205	293	315	363	315	363	383	294
357	286	183	240						

pen21

535	549	408	394	271	306	666	585	420	576
464	464	425	413	383	282	360	260	300	274
192	281	179	316	210	381	473	260	157	240
283	357	247	426	370	448	487	306	516	345
313	242	281	292	364	199	177	271	310	132
340	289	161	356	310	283	295	199	392	268
193	224	258	252	201	374	256	367	266	231
179	143	106	193	197	174	184	159	181	208
207	266	200	154	181	218	214			

pen22

296	195	329	295	289	255	155	193	217	223
189	220	238	219	372	323	323	216	89	195
217	135	230	211	311	292	167	188	207	148
100	78	92	106	88	144	98	169	115	103
80	127	177	91	180	204	242	204	118	82
75	60	57	57	76	165	213	122	146	104
181	159	135	147	180	224	170	127	107	132
91	76	110	89	191	126	88	119	157	103
130	97	201	133	132	85	50	73	76	

pen23

404	362	344	403	345	395	345	206	260	285
350	344	265	216	269	243	160	255	254	221
314	300	314	295	172	257	234	197	239	311
258	228	347	195	335	234	245	255	160	155
177	225	205	261	176	150	189	146	215	223
146	179	136	137	166	207	222	218	230	227
216	211	227	265	273	198	243	226	155	157
152	167	185	265	170	194	129	190	232	317
269	334	351	333	341	363	308	297	288	244
256	426	287	258	256	179	206			

pen26

170	179	207	240	307	237	325	345	361	286
203	254	335	276	193	304	265	297	227	158
262	185	98	166	185	149	196	289	218	301
175	218	194	176	160	163	137	157	128	133
188	231	185	214	140	125	233	147	232	198
141	167	122	121	151	201	148	146	126	135
169	183	159	134	129	124	122	132	233	193
160	188	183	197	152	135	162	103	153	189
138	108	136	159	177	185	193	131	165	210
167	167	135	166	131	97	185	247	159	234
170	127	131	127	225	202	196	267	226	329
272	194								

pen27

303	277	402	311	310	352	297	283	383	342
200	184	213	291	240	196	220	227	198	217
172	204	252	227	223	231	212	141	254	230
173	189	150	183	151	160	210	215	249	202
230	261	236	197	223	219	175	231	215	197
225	208	214	160	196	195	196	165	219	242
268	260	138	261	276	158	171	132	169	242
179	161	145	180	223	189	157	183	188	204
220	173	120	153	174	156	135	135	133	132
165	111	112	137	137	121	146	188	176	166
103	96	114							