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H M TOWER OF LONDON (TOL99 & TOL100) LONDON BOROUGH OF TOWER HAMLETS

THE TREE-RING DATING OF THE WHITE TOWER

SCIENTIFIC DATING REPORT

Dr Daniel Miles

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Summary

Between 1997 and 2005, 155 timbers throughout the White Tower were sampled, of which 133 dated. Drawbar socket linings, with felling dates of AD 1049–81 and after AD 1068 respectively, and a lintel felled in AD 1055–87, represent the first phase of construction, before *c* AD 1083–90. The second phase is represented by another lintel, felled in AD 1072– 1104, and a gutter lining felled after AD 1101. Other medieval fittings include a door of Baltic oak boards, dating to *c* 1350, and a door of elm and Baltic oak dating to *c* 1475. The main roofs were found to have been replaced in AD 1490, when the second floor was inserted.

Repairs from AD 1532–33 were found in two turrets, but dendrochronology failed to find documented repairs of this date in the main roofs. The floor of the naval and record stores was dated to AD 1602–3, following the reconstruction of the east chamber forty years earlier. Other repairs include a timber and iron tying system in the south-west turret, inserted during the documented brickwork reinforcement of 1618–19, ground-floor timberwork dating to AD 1732–33, related to the documented insertion of brick vaults in the basement, and a series of roof replacements and turret repairs in AD 1780–83.

Forty-three timbers produced precise felling dates, for seven of the ten phases studied. The dated material produced nine reference chronologies, which gave excellent matches with local and regional reference chronologies, suggesting that all the timber, other than the Baltic oak used in the two doors, grew near London.

Keywords

Dendrochronology
Standing Building

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Frontispiece: The Tower of London from the air, with the City of London in the background and Tower Bridge in the foreground (copyright Historic Royal Palaces)

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Introduction

The scarcity of surviving medieval carpentry from castles in England and Wales is an obvious result of their being dismantled or abandoned, but it serves as an important reminder of the rarity of the Tower of London as a continuously occupied fortress. The surviving timber buildings, roofs, partitions, doors, and portcullis machinery in the Tower are valuable examples of royal carpentry and London practice, though they have attracted relatively little attention (Hewett 1980).

Major building works and associated repairs in relation to a representation programme for the White Tower undertaken in 1996–8 provided a unique opportunity to investigate the historic fabric of the building. As part of a multidisciplinary research project organised by Historic Royal Palaces, the Oxford Archaeological Unit was commissioned to examine the carpentry of the White Tower and draw up a programme of tree-ring dating. While the resulting dates were not in themselves surprising, they assisted greatly in dating the various timber elements which were generally devoid of characteristic features that might otherwise have allowed more precise stylistic dating.

Interim results from the initial dendrochronology programme were published in the tree-ring date lists in *Vernacular Architecture* (Miles and Worthington 1997) and presented at the EuroDendro - 98 Conference the following year (Miles and Worthington 1998). This resulted in a total of eight replicated site master chronologies being produced at this time. These publications represent the majority of the dates presented in this report. Subsequent research includes the dating the first-floor niche lintels, a western drain timber, and most recently in 2005 the dating of beech timbers from the bottom of the well, and further sampling of the main roofs. This report draws together all of the tree-ring dates produced for the White Tower, together with a descriptive analysis of the timberwork sampled. Much of this research in the historic woodwork of the White Tower will be included in the 'Medieval and Later Carpentry and Woodwork' appendix by Julian Munby and the author in *The White Tower*, edited by Dr Edward Impey (forthcoming).

Description of the White Tower

The White Tower (TQ 336 805) is situated within the great medieval fortress of the Tower of London, traditionally thought to have been built by William the Conqueror beginning in 1077, at the point of where the eastern Roman fortifications abutted the north side of the River Thames (Figs 1 and 2). It is the main keep of the castle and measures 118ft by 106ft (36m by 32.3m), and rises 90ft (27.5m) on the south side, with walls up to 15ft (4.5m) thick at its base (Impey and Parnell 2000). When originally constructed, there were three basic levels within the main part of the Tower: the basement level, the principal entrance or ground floor level, and the first floor (Figs 3 and 4). This upper floor comprised a large hall taking up the entire western half of the building, whilst on the eastern side was a smaller room at the north end which served as a chamber, and the Chapel of St John with a semicircular apse, to the south (Fig 5). What is not known is what the suite of similar-sized rooms below on the ground floor was used for, although one suggestion is that it could have been used by the Constable of the Tower. Above this level on the first floor the walls continued upwards to form an internal gallery within the chapel, and around the perimeter walls and over the central spine wall to form a false second floor with battlements above. The pitched roofs drained into drains running under the second-floor mural passages along the east and west walls, with a central valley between the two roofs over the spine wall. This created an external appearance of a building more massive than really existed behind the false second storey walls and battlements. At each corner there is a turret, that to the north-east being circular and known as the Flamsteed Tower.

Later in the medieval period the White Tower was used less for Royal lodgings and other occasions such as the ceremony of the Knights of the Bath. At this time the roofs were removed and nearly-flat lead roofs constructed one storey higher, just below the top of the false walls and battlements, and a new second floor was inserted. From this time the White Tower was used for the storage of munitions, and by the seventeenth century the whole of the top storey was used for the storage of gun powder. This use seems somewhat incompatible with the use of the Chapel of St John as the repository for state records from the late-thirteenth to the mid-nineteenth centuries.

The Primary Norman Phase

No structural carpentry survives from the Norman White Tower, and it is largely a matter of speculation how it was floored and roofed in its earliest phases. Nevertheless, three most interesting finds of wooden components, most of which directly related to their surrounding masonry, survive. These are firstly the wooden linings of the drawbar sockets by doorways (eg in the spine wall of the first floor), secondly the wooden lintels of cupboard recesses on the first floor; and thirdly the wooden lining of the external drains in the passageway at Gallery level. Through a careful study of the drawbar sockets and their relationship to the jambs, it is possible to gain some clues as to what the original doors would have looked like. In addition to the above, the beech timber support for the well has been investigated.

Basement Doors

In the basement, evidence remains for there having been three doors from the primary Norman phase of construction. The first is at the bottom of the Great Vice at the north-east corner of the east room (Fig 6), the second is at the west end of the short passage between the east and west rooms at the north end of the spine wall, and the third at the south end of the east end into the basement apsidal basement room under the chapel crypt, although the jambs have subsequently been removed (Fig 7). However, the clearest evidence for the original Norman door arrangement can be found in the passage and doorway between the east and west rooms. This door was set back 2ft (600mm) from the face of the wall, the reveals protruding 6in (150mm) to form the jambs. A drawbar socket 6ft 7in (2m) deep is set in the south wall, the bottom of which is 4ft 1 in (1.2m) above the original floor level (Fig 8).

The door would have originally measured up to 4ft 8in (1.4m) wide and 8ft 6in (2.6m) high to the spring line of the rear-arch. As the top of arch to the stone jamb is lower than the spring line of the passage vault, the door itself would have had a square head. The fact that the drawbar socket lining is set 3in (75 mm) from the back of the reveal would suggest that this was the thickness of the original door.

The drawbar socket to this door was originally lined with oak, the top board of which remains *in situ*. This is the only surviving piece of original Norman timberwork on this level of the White Tower. To allow the drawbar to slide smoothly in and out of its socket in the rubble wall fill, a wooden lining was constructed in which it was housed. This took the form of a box made up of four riven-oak boards 18–25mm thick, which were finished smooth with a plane. The bottom board was set between the side boards, and the top board sat over the side boards, and all were nailed together. The draw bar would have measured slightly less than 4in (100mm) thick and up to 5½in (140mm) high and it would have to have been placed in the box, and the whole assemblage placed in position as the walls were being raised and before they were covered over by subsequent courses. These, therefore, would have been the earliest pieces of timber to be built into the White Tower, in the first season or two of construction, thought to have commenced in the 1070s.

Ground-Floor Doors and Drawbars

On the principal ground floor, there remain two doorways which retain their timber-lined drawbar sockets, one in the spine wall cross-passage and the other at the main south entrance. The first is at the western end of the southern cross-passage between the east and west rooms (Fig 9). The drawbar socket was rediscovered during the 1996-7 survey, having been plastered over with mid-twentieth century hard cement mortar. Once the blocking was removed, the timber lining was found to be in a perfect state of preservation. It is of the same size and construction as the one described in the basement spine wall, but extends slightly deeper into the wall to a depth of 6ft 10½in (2.1m). This drawbar was set in the north side of the spine wall, but its receiving socket on the south jamb is missing due to the replacement of some of the masonry. Evidence for a similar door exists at the north end of the spine wall, although the jambs have been cut back and the drawbar sockets blocked.

Impressions of the original Norman shuttering boards are clearly evident in the two cross-passages in the spine wall, and these measured ½in (13mm) thick by 3–5in (75–125mm) wide and about 4ft (1.2m) long. Two fragments of boards still survive over the southern cross-passage, trapped between the stonework over the jambs and the passage vault.

At the south entrance, there remain two drawbar sockets 11ft 6in (3.5m) deep. The lower one is 2ft 6in (760mm) above floor level and is in the west jamb (Fig 10), with the upper socket built in the east jamb. The original drawbar would have measured 5½in (140mm) wide and 6½in (165 mm) high, and the lining boxes were constructed in a similar method as the ones in the internal spine wall, with the exception of the side boards, most of which are cut back about 11in (280mm) from the front, and the stonework is similarly cut out to allow the stone to form the actual side jambs of the opening. What is unusual is that the bottom opening has the stone reveal on the south side only, the north side has the timber board extending all the way to the wall face, as do the top and bottom boards. That the boxes vary slightly may suggest that co-ordination between the carpenters and the stone masons was not as good as it should have been, and the facing ashlar had already been laid before the boxes were constructed and the mass walling built around. The upper pocket on the east side has been blocked with some mortared stones at a depth of 2ft (600mm), but the lower pocket on the west was open, and it was possible to removed some fragments of timber still laying in the back of the socket. Among the fragments was also found a fourteenth-century spearhead, the oldest piece of armoury to be actually related to the Tower of London (Robert Chester *pers comm*). The principal south entrance retains evidence for the thickness of the original doors by comparing the offsets between the edge of the drawbar socket lining and the inside edge of the jamb, which are 3¼in (83 mm). Assuming that the greater depth of the socket boxes necessitated a looser fit around the drawbar, it is reasonable to conclude that the main south doors would have measured about 3½in (89 mm) in thickness, which is about ½in (13 mm) thicker than the internal doors. The overall width of the pair of doors would have been 8ft 7in (2.6m), and the total height would have been no more than 12ft 6in (3.8m) due to the curvature of the vault. It is not known how the tympanum over the doors was configured, for the jambs do not continue in an arch beneath the vault, but instead stop where they intersect the vault. There is no obvious blocking for a removed timber lintel or beam.

Although none survive, it is possible to address the question of what the Norman doors would have looked like. Using the evidence of the offsets from the drawbar sockets, we have been able to determine that the internal doors through the spine wall were about 3in (75mm) thick, whilst the south entrance doors were probably slightly thicker, at least 3½in (90mm) thick. The outstanding question is whether the doors consisted of a single covering of planks or boards on a framework, or whether they were built of two or three layers of boards. Only a few English doors survive which are broadly contemporary – the slightly earlier Pyx door from Westminster Abbey (AD 1031–63) (Miles and Bridge 2005), the north door at Hadstock (*c* 1066) (Miles *et al* 2003), the Gundulf door at Rochester Cathedral (AD 1075–1108) (Miles and Worthington 2002), Durham Cathedral (AD 1099–1134) (Caple 1999), and the Kempley doors (AD 1114–44) (Miles *et al* 1999). All five of these doors consist of a single layer of boards or planks between 1¼in (32mm) and 2in (50mm) in thickness. The Westminster example is held together simply by the hinge bands, as possibly might have been that at Rochester. The Hadstock and Durham doors have rounded ledgers on the back, as may have that at Kempley. Slightly later are the main gates from Chepstow Castle (AD 1159–89), which consisted of 2¼in (57mm) thick planks on a lattice of 2½in (65mm) thick diagonally-set ledges (Avent and Miles 2006). This is a useful example in that both the gates and drawbar sockets remain to allow a comparison to be made. The hanging styles at Chepstow measure 5in (125mm) thick, whilst the offsets from the inner face of the drawbar socket are 4in (100mm) back from the face of the jamb. It is not obvious whether there was a timber lining to the sockets at Chepstow, but this demonstrates that the thickness of the doors would not be *less* than the distance from the jambs to the drawbar socket reveal.

It is therefore likely that the 3½in (90mm) measurement of the set-back of the socket from the edge of the reveal of the south doors at the White Tower would indicate the doors themselves were unlikely to vary much either side of 4in (100mm) in thickness, with a drawbar of about 5in (125mm) in thickness. However, as hanging styles of 4in (100mm) would not really be sufficient for doors of this size, a composite door built up of a number of planks is more likely. The best, and most local, parallel would be the *c* 1350 basement door (see below) in which three layers of boards were used. Boarded doors of two layers used externally have a habit of warping when exposed to weather, but three layers balances well any tendency for the timber to warp in relation to moisture and heat. Therefore, it is likely that the door was built up of three layers of boards at least 1¼in (32mm) thick, with the centre boards running horizontally. Such a composite door would give immense strength. Indeed, the existing *c* 1350 basement door survived a bomb blast not more than 25ft (7.6m) away in 1974 with hardly a scratch.

The boards used in the doors would have been of good quality oak, as found in the timber linings to the drawbar socket linings. They would have been riven, and would probably have finished between 6in (150mm) and 8in (200mm) in width. Certainly edge dowels or pegs would have been used to joint the edges of the boards together, and they may have been rebated, as were all the early examples quoted. Some use of free or slip tenons may also have been used together with the iron hinge bands and other decorative ironwork to keep the boards together. The doors would have been manufactured to a high degree of precision, befitting a Royal building of the highest importance.

As for the internal doors for which we have evidence, the offset from the reveal to edge of the drawbar socket lining of 2¾–3in (70–75mm) would suggest a door leaf 3–3¼in (75–83mm) thick, allowing for a drawbar up to in (100mm) in thickness. Again, given the defensive nature of the building, it is likely that these doors would have resembled the later door of the basement apsidal room, which is 3in (75mm) thick. Indeed, it is quite possible that the original Norman doors were used as a pattern when this door was constructed.

First Floor

On the first floor is a series of recesses in the window embrasures – four in the southern two alcoves in the east wall and four in the northern two alcoves in the west wall. They are of the primary construction, and are variously just above (east room) or below (west room) the level of the building break, and were perhaps all built as cupboards. These recesses are noticeably variable both in size and in height above the floor. All the recesses have timber planks which serve as lintels, upon which the mass masonry was constructed. These planks are tangentially converted, but were initially converted through splitting and hewing (Fig 11). Several planks on the eastern niches are radially-split, and least two planks have redundant peg holes, suggesting reuse (Fig 12). They average 1½–2¾in (38–70mm) in thickness and vary in width between 7in and 15½in (180–390mm). Two lintels in the second embrasure from the north on the west side have rebates for a missing cupboard front.

Second-Floor Wall Drains

The final area of Norman woodwork to be studied is the timber formers or gutter liners found in the drains under the second-floor mural passages that were observed during the replacement of the floor in 1996. A series of drains was found crossing under the western mural passage, some of them with remnants of timber and lead lining. A 2ft (600mm) section to Drain 4 under the west passage was discovered relatively intact, although relatively friable (Fig 13). This single piece of wood had been hollowed out to form the drain, 6½in (165mm) wide and 2½in (65mm) high, inside a wider and deeper channel in the stonework. Another was found in Drain 8 on the west side (Fig 14), but was broken up into two dozen small fragments, with a width of ½in (13mm). Both of these seem to be rather small to cope with large amounts of water resulting from a heavy downpour, but the single lead covering which still survives in Drain 3 does extend significantly wider either side, suggesting that it could cope with excessive rainfall.

Two more fragments were located under the eastern mural passage, quite different in form (Fig 15). These were from a single, fractured, board, ½in (13mm) thick and about 9in (225mm) wide, found lying on the bottom of the gutter channel.

The Norman Well

In the south-east corner of the west basement room is a circular stone-lined well 40ft 6in (12.4m) deep below present floor level, and measuring internally 5ft 6in (1.7m) diameter at the bottom and 5ft 4in (1.6m) at the top. The stonework is of diagonally-tooled Caen stone, laid in courses varying between 6in and 8in (150mm to 200mm) high and 9in (225mm) thick. The mortar used in the construction of the stone lining is a coarse, gritty light mortar not dissimilar to that used in the second (upper level) construction phase of the White Tower, dating to after *c* 1090. Currently there is some 28ft (8.5m) of water in the well, 12ft 6in (3.9m) below present floor level.

The stonework of the well lining sits on a timber base or template which is a fundamental part of the construction process (Fig 16). In sinking a well which is not through a solid substrate such as chalk, the stone or brick lining is constructed at ground level in a shallow excavation in which is laid a timber template or kerb. After constructing the lining to a height at least the diameter of the well, the earth is dug out evenly from inside the well lining, undermining the timber kerb, and thus allowing the entire well lining to settle down into the shaft being excavated. At the White Tower, a pair of cross-timbers 2 × 2½in (50 × 65mm) in cross-section, the broken ends of which are still *in situ*, was built into the stone lining approximately 4ft (1.2m) above the timber template. This presumably provided additional temporary support to the incomplete cylinder of stone as it started to descend as the shaft was undermined. As the lining sank, more courses of stone were constructed on the top at ground level, and every seven or eight courses five or six substantial put-logs 4–6in (100–150mm) wide by 7in (175mm) high were built into the stonework, forming temporary stages or lifts to access the bottom of the shaft during excavation (Fig 17). The third course of put-logs from the top consisted of only five timbers, suggesting that the radial putlog timbers were supported on a centre post. Once the water level is reached, the digging process become much more difficult in that one has to dig underwater, but no doubt the water was bailed as much as possible to allow a greater depth to be reached. Once the final depth had been reached and the masonry lining settled to its final position, the stonework would have been completed at floor level, and the timber put-logs removed.

Generally, the timber kerbs or templates to the well bottoms were of four or more thick timbers jointed together, following the curve of the well lining. Examples recently excavated include the early medieval well at Merton College, Oxford, and a seventeenth-century example at Brockton Farm at Charing, Kent; however, the arrangement found at the bottom of the White Tower well is unlike anything previously excavated (G Milne pers comm). Here the kerb was constructed of beech (*Fagus sylvatica*), a material generally used for underwater works, and used as piles under one of the demolished western defences dating to 1241. Beech is not often used above ground, as it is prone to beetle attack. Underwater, it is even less satisfactory, in that it becomes very weak when submerged for long periods, possibly resulting in structural collapse. The use of beech in structural carpentry seems to have become popular during the Norman period, after which it fell out of favour, most probably due to its poor performance underwater (I Tyers pers comm). The kerb is composed of a series of nine planks varying in width between 8½in (215mm) and 10¾in (273mm), and between 1¼in (32mm) and 2½in (65mm) in thickness. They were riven from a large tree of at least 30in (750mm) diameter and finished square-edged. Unusually, the planks were laid parallel running north-south in a single layer, with only a few fastened together by square beech edge-pegs or dowels. What is unusual about this arrangement is the apparent lack of strength in an east-west direction. Here the short lengths of plank are simply butted together, and on at least one dislocated segment there is absolutely no evidence for any edge pegging, or any peg holes on the face suggesting any connections to a second layer of cross-planking. Without any other form of support, the short lengths of plank under the north and south ends of the well would simply fall out.

Unfortunately only four planks remain *in situ*, of which a small slice from a fractured end was obtained (Fig 18) with a short length of a second plank recovered directly below its original position (Fig 19). Three other sections of plank were recovered from the mud in the centre of the well (Figs 20–22). The well had been subsequently deepened by about 2ft (0.6m), necessitating the shoring up of the kerb firstly by four softwood pit props measuring 4¼in (108mm) by 5in (125mm), and secondly by the insertion between these of three courses of reused dressed stonework (Fig 23). Two of these are in the form of narrow piers, allowing the partial underside of the four *in situ* planks to be inspected at least by feel.

So how did the template work whilst the well was being dug? The most likely possibility is that the planks originally extended right across the bottom of the well, with only a small access opening in the centre through which the earth was excavated. If this were so, then there could have been additional east-west planks laid over the surviving north-south planks as far as the inside of the stone lining. Once the bottom was reached, all of the upper-level timberwork from within the shaft lining was removed, and the bottom planks would have been cut back to the line of the inside face of the stone lining. Examination of the surviving *ex situ* planks would support this hypothesis in that the outer face of the planks is neatly cut following the line of the outside of the well lining, whereas the internal line is crudely chopped, not unreasonable considering that it would have had to have been cut underwater. This would have left the short ends of the planks in place, clamped between the stonework of the well above and the London clay below. The shorter planks were undermined and fell into the mud when the well was subsequently cleaned out.

The well was filled in 1734 to keep the damp from affecting barrels of saltpetre stored in the basement (Fox 1912, 84–5). When the well was last pumped dry, in April 2005, it was found to contain half a dozen cannon balls, bottles, a pair of old boots complete with socks, and a large quantity of copper coins, none of which dated from before about 1900.

Medieval Fittings

In addition to the door reveals and drawbars described above, there are three surviving medieval doors.

Door I – Fourteenth Century

This is the medieval door in the basement of the White Tower, in the round-headed cross-passage between the apsidal basement room and the east basement room (Fig 7). This doorway originally had a jamb at the south end, with evidence for a drawbar socket and hinges on the west wall. The floor level here is thought to have always been at the present level, some 2ft 6in (762mm) lower than that at the north end of the basement. At some point the jambs at the south end of the passage have been removed, and a rebate cut in the north end of the cross-passage to receive the present door. This is very well made of three layers of oak boards, each 1in (25mm) thick and 5–8in (125–200mm) wide, aligned vertically on the outsides and horizontally in the middle. The boards are not rebated and have square edges, joined edgewise with ¼in (6mm) square pegs of uncertain length set at 11in (275mm) to 12in (300mm) centres. Clench nails have been driven in a regular 5¼in (133mm) grid from the (north) inside through the layers of boards to the (south) outside, where their ends are clenched over. The hinges are doubled, each hinge having both a plate on the outer face, and a second one passing between the two inner layers of boarding.

Door II – Fifteenth Century

The door from the basement to the north-east stair turret is a medieval door of less substantial character than the first (Fig 6). It has only two layers of boards, but they are a little thicker at 1¼in (32mm), the outer one of vertical 8in (200mm) wide oak boards, and an inner face of horizontal 9–10in (225–250mm) elm boards. As in the other, earlier, door at the south end of the east basement, the oak boards are jointed together with $^{3}/_{8}$in (10mm) diameter dowels which are here set at 13½in (345mm) centres. The boards are fixed together with clenched nails set at a 4in (100mm) square grid. The door is hung on the west side with three bands sandwiched between the two layers of boards. The use of elm for a door in any situation is unusual, and although it is just possible these backing boards are a later addition, it is unlikely.

Door III – Sixteenth Century

There remains one early external door on the south side of the White Tower. This is at the bottom of the small vice leading up to the first floor and the chapel entrance passage (Fig 24). This small, round-headed, doorway was a later insertion, perhaps late medieval, and measures 6ft 7in (2m) high and 2ft 10in (850mm) wide overall. The front, south, face consists of two broad planks 17in (430mm) wide and 2in (50mm) thick. This is backed by four horizontal planks, the top and bottom planks 17in (430mm) wide, and the middle planks 22in (560mm) wide, all again 2in (50mm) thick, making a substantial door 4in (100mm) thick. The planks are tangentially sawn from a large, fast-grown tree, precluding dendrochronological analysis. The timber was undoubtedly of local origin. The two layers of planks were fixed together with about 30 large, 6in (150mm) nails, the heads measuring 1–1¼in (25–32mm) square, heads ½in (13mm) deep, set diagonally. The door is hung on two large bands, hinging on the east and opening inwards.

Later Medieval Floors and Roof

Undoubtedly, the most outstanding features of the surviving White Tower carpentry are the low-pitched late-medieval roofs (Fig 25). Covering almost a quarter of an acre (almost 1000 square metres), the main roofs are the largest surviving example of medieval carpentry in the Tower. The roofs are divided into three principal sections, spanning the great west room, which covers the entire west half of the building and measures internally about 96×41ft (29.3×12.5m); the smaller east room, measuring internally 65×30ft 6in (19.8×9.3m) and extending a further 40ft (12.2m) southwards to cover the chapel vaults, with an eastern monopitch extension of 25ft (7.6m) over the eastern apse. The roofs all run north-south with parapet gutters over the east and west mural passages, and a central gutter supported by the Norman spine wall.

Roofs of this sort were designed for a covering of lead sheets, and are typically of late medieval design, usually found in fifteenth or sixteenth-century church roofs as described by Howard and Crossley (1917), although an example dating to 1247 has been recorded in Shropshire at Great Oxenbold, Monkhopton (Miles and Haddon-Reece 1993). Here the roofs employ an enlarged tiebeam known as a 'firred beam', rather than a truss employing collars, struts, or rafters. The massive tiebeams run east-west and are supported on double wallplates. The upper wall-plate, measuring 11in high and 7in wide (280×180mm), acts as a lower purlin or cornice plate and is rebated over the edge of the lower plate which forms the bed of the gutters and is 8in (200mm) thick. The upper plate is also tenoned into the sides of the tiebeam. The tiebeams are of exceptional cross-section, measuring 17–20in (430–510mm) wide and 27in (685 mm) high in the centre, reducing to 16in (400mm) at the ends.

The overall length of these beams is even more exceptional: those over the chapel and eastern room at over 32ft (9.8m) long are outstanding, whereas the western room tiebeams with total lengths in excess of 43ft (13.1m) are at a scale quite without precedent in England. Few buildings have clear spans of over 30ft (9.2m), and these are roofed not by single unsupported beams as found in the White Tower, but by trusses incorporating braces and hangers, thus reducing the weight supported by the tiebeams, often even removing the tiebeam entirely, as in Westminster Hall and King's College Chapel, Cambridge. The widest broadly-contemporary low-pitched roof truss is that of the Chapel of St George, Windsor, at 36ft 6in (11.1m). The importance of these roofs cannot be overstated in terms of sheer scale, not only in the length of the principal beams, but of the length of the roof as well. The King's Royal forests would have had to be extensively searched to find such exceptional timbers, and after cutting to size, they would have still weighed about 3.5 tonnes. The logistics of converting these gigantic trees, transporting them from the forests to the centre of London, and hoisting up into place upon the walls would have been considerable. However, these efforts were clearly considered worthwhile despite the fact that the Tower was becoming of less importance as a Royal palace.

It was not until the seventeenth century, when Sir Christopher Wren designed engineered trusses for St Paul's Cathedral in London and the Sheldonian Theatre in Oxford spanning 50ft (15.3m) and 68ft (20.7m) respectively, that the White Tower roofs would be surpassed.

With many of the tiebeams, it was not possible to obtain the requisite thickness at the centre to maintain the required fall of 2½ degrees; such deficiencies were made up with an added packing or firring piece up to 6½in (165mm) high) slotted into the top of the tie and secured by under-squinted abutments at each end, square on plan, and jointed along the edges with a series of secret, or slip, tenons at about 20in (*c* 500mm) centres. Skilfully executed and wedged together at the ridge, these inserts actually prestress the beam, giving it more resistance against settlement to the upper face of the beam, which then acts in compression.

The tiebeams carry a series of butt or tenoned purlins 9×11in (225×280mm) in cross-section, two on either side of the ridge piece on the eastern roofs, and three on the western roof. The purlins are tenoned to the ties with the late-medieval type of tenon with a diminished haunch. The common rafters measuring 7×5in (175×125mm) rest on the upper wallplates and purlins, but are jointed into the ridge with central tenons with ½in (13mm) haunches on either side. There are five rafters to a bay in the west room and five or six to a bay in the east room and over the chapel.

The large west room is divided into ten bays by eleven tiebeams, including a tiebeam against the north and south walls. The smaller eastern room roof is divided into seven bays but, unlike the western half of the roof, there is no end tiebeam against the north wall. Similarly, the chapel roof consists of four bays with three tiebeams, but none against the southern wall, although the first tiebeam in the chapel is supported on the stone dividing wall between it and the east room.

There are some differences in the Chapel roof, which has to accommodate the eastern apse extending beyond the rest of the roof space. It has a substantial trussed beam 20in wide by 11in deep (510×280 mm), supported at each end on posts 14in (360mm) wide at the base and thickening to 20in (510 mm) at the top to align with the wall plate. The plate was further supported by two braces which rise over the stone vault of the chapel ceiling below, and two more from the posts over the aisles. Beyond this plate the apse end is roofed with a gentle monopitch of rafters supported on north-south purlins, each supported on pairs of posts resting on pads or sill-beams. Although these arrangements may appear superficially to be part of some earlier roof they are clearly contemporary with the remainder.

Only the upper wallplates/cornice plates and tiebeams are finished with a large chamfer varying from 45 to 60 degrees and measuring about 2¾in (70mm) wide on the plates and 3½in (89mm) wide on the tiebeams. All chamfers on the tiebeams have matching straight-cut stops in line with the plates forming a mason's mitre in effect. The chamfers on the upper wallplates in the west chamber have a slightly hollow profile (Fig 26).

Despite the defacement of the timbers in the large east and west rooms through the sanding of the surfaces during the 1950s restoration, some of the assembly marks could still be made out. The roof over the chapel was relatively unrestored and could be easily accessed from the stone vaults, and the sequence of assembly marks could be clearly discerned. It would appear that each tiebeam was numbered from I to IIII, starting with the now missing truss over the stone wall between the chapel and the eastern room. The assembly marks are scribed on the southern face of each truss, adjacent to each purlin, with a corresponding mark on the northern end of the purlin. Those on the west side of the ridge were distinguished from those on the east by the use of a tag, or oblique stroke. Rafters were numbered at the top on their southern face, with a corresponding mark on the side of the ridge, but only at the most northern rafter mortice, it being left to the carpenters assembling the roof to count along the ridge to correctly position the remaining rafters in each bay. Bays I (northernmost bay) and bay IIII have six rafters, whilst the middle two bays have five rafters. In bay I the eastern rafter I has replaced rafter VI, with a new timber inserted in the place of rafter I. This pair of rafters has been moved further south to accommodate a modern brick wall on the south side of the tiebeam I during the twentieth-century restoration.

The east chamber roof has been very heavily sanded, and therefore only a couple of assembly marks could be made out on the east face of the ridges: a IIII on the fourth bay from the north, and a VI on the sixth bay from the north which then abuts tiebeam I over the cross-wall belonging to the chapel roof. This suggests that as in the chapel roof, the timbers were numbered from the north, but without the northern-most tiebeam which would have been numbered I. Despite being framed up in two separately-numbered frames, these roofs were clearly constructed at the same time, as the ridge in bay 4 in the east room was cut from the same tree as the ridge from the second bay in the chapel roof (see Interpretation and Discussion).

More assembly marks were recorded on the large western roof, and the same method of marking was employed, starting at the north end. Although this roof differs from the chapel and east room roofs which have no end tiebeams, the bay numbering is identical.

The southern-most beam in the west chamber retains evidence for an interesting wall framing arrangement against the north face of the southern mural passage. Two lines of 4in (100mm) mortices in the soffit, staggered 8in (200mm), are set at 2ft (600mm) centres (Fig 27). These extend across the middle half of the wall and were clearly inserted at the same time as the roof was constructed, for the southern row of studs has been pegged from the south, and the northern line of studs from the north. On the east end they terminate at a substantial spandrel brace and wall-post, about 10ft (3.1m) out from the spine wall. Presumably the same arrangement existed at the west end, although the soffit of the beam has subsequently been repaired, removing any evidence.

Related to this is the adjacent ridge beam in the southern-most bay. Here, the soffit and the sides, up to the underside of the ceiling joists/rafters, were decorated with iron tacks, forming a series of chevrons (Fig 28). Presumably these tacks were used to fix some coloured material to form part of a decorative scheme. Together with the (presumably) decorative woodwork on the adjacent end wall, this would have formed an impressive backdrop, although just what this would have been used for is open to speculation.

There exist detailed documentary accounts (TNA SP1/85, fol. 73r; accounts in Bodl MS Rawlinson D 777 and Nottingham, Newcastle MS Ne 02) suggesting extensive repairs to both the east and west room roofs in the mid-1530s, but not so far as to suggest that the roofs were replaced entirely at this time. A report in July 1534 stated that the roof of the White Tower required '*great reparacions*', and in the following February work had begun on *the Trussing of the Beames with brases in the Rouffe of the southsyde of the whyte Toure.* The works included replacements of at least one 'great beams' with pendants and braces on the south side of the White Tower, and continued into 1536, with the replacement of a 'great beam' at the north end, and specific reference to 'strengthening' the roof; they were terminated by leadworking and gutter repairs in late 1536. The construction of two 'great scaffolds' on three sets of wheels from which to carry out the work below the roofs would seem to be quite a technical achievement in itself, although entries referring to repairs suggest that the scaffold was not without its problems.

Similarly, the documentation of two windlasses or tread-wheels constructed on the roof illustrated the lengths to which it was necessary to go in order to raise the 'great beams' from the ground up to the top of the roof, which suggests that these documents referred to the installation of new tiebeams. However, references to at least four pairs of screw-jacks indicate that some of the roof had sagged to the extent that it was necessary to jack up some of the existing tiebeams as the bracing was inserted beneath.

The documents would suggest that some serious decay was evident in the wall plates under the gutters, and this had affected the ends of the tiebeams, at least one or two of which required complete renewal. This required the lifting of leads, roof boarding, and effecting repairs and replacements to the plates on which the tiebeams rested. Apart from the replacement of a tiebeam or two, the bearing ends of others appeared to be weakened to such an extent that they needed shoring by the insertion of wall posts and braces up to the underside of the tiebeams. These posts extended right down to the floor below, some of these clashing with the openings to the mural passages. Evidence of these 1530s posts and braces can be found on Lemprière's 1729 section drawing of the Tower (Fig 4), but the braces had already disappeared when the same room was drawn in 1754, leaving the tiebeams directly supported by two posts in the centre along the line of the lower floor arcades (Fig 29).

So what caused the roof to require such a major overhaul? The most likely scenario is that when the roof was originally constructed, the gutters had insufficient fall or some other defect in the lead covering which periodically let in water, causing decay in the wall plates, and affecting the ends to the tiebeams, through wet rot, or possibly dry-rot and/or death-watch beetle infestation. This was no doubt compounded by the inevitable deflection in the western room tiebeams – at over 40ft (12m), unseasoned, slow-grown oak, will deflect under constant load, and with such a low pitch of 2½ degrees, water would probably have blown up under the laps in the leads during windy conditions.

The later history of the roof can be shortly dealt with. A number of firring pieces were inserted on the rafters, probably in 1604/5 (TNA E351/3240) to even out the roof slope and to increase the fall which had been reduced by the sag in the tiebeams. Existing skylights were enlarged in both halves of the roof in 1858 by Salvin to illuminate the displays beneath (openings in second floor sent the light down to the first floor). At the same time the tiebeam ends were further supported by brackets or consoles which were constructed of wrought iron, clad in timber. Further major timber repairs were made to the roof in 1955, and it is likely that during this period the northern two tiebeams in the east room and the northern beam in the west room were replaced entirely. However, the extent of the decay in the remaining principal beams was such that finally, between 1960 and 1965, as was then the fashion, an entirely new roof support of steel was built on top of the medieval roof, with the intention of suspending the timbers from above. This was rather a sorry end for a roof that as late as 1600 had been capable of supporting sixteen cannon pointing at the City, but despite these changes the strength of its original form can now be appreciated.

Elizabethan Floors

The flooring of the main spaces of the White Tower has been changed once if not twice. The spans in excess of 30ft and as long as 40ft (9–12m) could have been covered by large joists, but their strength depended on the condition of their junction with the wall, where rot and insect attack was most likely at a point where the ends of the beams were able to take in moisture. They would undoubtedly have required one or two arcades below to give intermediate support to the beams.

On the second floor the infilled sockets were found on the west wall which either related to the original Norman roof or the later-medieval floors. The floors were replaced in the sixteenth and early-seventeenth century when the present heavy-duty floors were inserted for military stores (and in the eighteenth century by the insertion of vaulting in the basement). In order to reduce the span of the rooms, intermediate supports were created by the insertion of rows of posts or columns carrying large joists on which the floors could be laid, with a maximum span of between 10ft (3.1m) and 16ft (4.9m) for the individual areas of flooring.

Ground Floor

The floor at the entrance level has been truncated from beneath by the insertion of vaults in the basement in the eighteenth century (Fig 30). Lemprière's section of the White Tower in 1729 shows a row of columns in the basement (Fig 4), and the western half appears to have the remains of two rows of timber columns (shortened and now resting on the vault) and a north-south run of principal joists. Lemprière's plan shows the arrangement of racks in the western division for the Sea Armoury (Fig 31), and in the eastern division for a tool store, and a number of openings in the floor (especially in window recesses) to allow light into the basement (the chapel basement vault contained the Ordnance Office records). The columns supporting the first floor show some signs of the attachment of racking, and at least one has a regular array of marks indicative of the display of arms.

First Floor

The first floor is supported by two rows of ten columns in the west division (two rows of six in the east). These carry principal joists aligned north-south, into which secondary (east-west) softwood joists are lapped at bay intervals (Fig 32). In the western division the secondary joists are staggered so that they do not coincide where they meet the principals, whereas on the east side they are aligned on the columns (and are also within the depth of the principals rather than passing over them). The common joists for the floor rest on the secondary joists and run north-south. The arrangement of the timbers (as seen in the ground floor ceiling) is obscured by many of the timbers being boxed out to give them a uniform appearance, and the observations on the hole made at the north end of the western division for a new staircase showed that there were several layers of floorboards. The common joists are not visible on either side: the east division has a pine-boarded ceiling, and the west is plastered.

First Floor Rooms

Lemprière’s plan (Fig 32) shows the arrangement of storerooms in both east and west divisions for Small Arms, and a trap door in the north-east corner of the western division to allow materials to be raised from below (the Chapel contained ‘Part of the Records of England’). As below, the columns supporting the second floor retain traces of their former attachments, with horizontal slots for three tiers of shelves and in some instances vertical slots into which arms could be fitted for display.

Second Floor

The second floor is supported by an arrangement of columns similar to that of the floor below. The columns carry discontinuous principal joists aligned north-south, on which rest the secondary (east-west) joists. In the western division there is a continuous series of closely spaced secondary joists, so that a tertiary series of joists was not necessary; whereas on the east side there are three sets of joists as on the floor below. There is a gap in the joists for a possible trap door in the north end of the west division, though not exactly as shown by Lemprière (Fig 29).

Second Floor Rooms

Lemprière's plan of the upper floor shows an open storeroom on the western division for *'match, ropes, shovels, wheelbarrows, etc*' (Fig 29). The plans shows rows of columns that are no longer there (but not attached to any racking), and towards the north end a *'Capstan for drawing of stores up from the Rooms below thro' a Trap Door'* (the trap is immediately above that in the first floor below). The eastern division was connected through to the Chapel gallery and both of these held racks for '*Part of the Records of England'*. There are no surviving posts at this level, and the medieval roof has been described above.

The Turrets

The four stone turrets above the white tower surmount the spiral stairs in three corners, and the fourth in the south-east corner rises above the Chapel vault (Fig 33). Three of the turrets are square towers, whereas the north-east one over the large stair is approximately round; known as the Flamsteed Tower, the upper room was briefly used as an astronomical observatory in 1675 by John Flamsteed. With their 'onion' shaped roofs the turrets were the feature that made the Tower a prominent landmark, but their date was unknown, and it could only be speculated that their ogival shape was of late fifteenth or early sixteenth-century date when this motif was revived.

The North-East Turret

The most interesting roof is that of the large near-circular Flamsteed Tower (Fig 34). This is based on a principal north-south joist 10×11in (250×275mm) in cross-section, with four secondary east-west 10×6in (250×150mm) joists tenoned into it (with a double tenon having a shouldered tenon below and a diminished haunch tenon above) and a central square formed of two additional timber plates laid on the secondary joists (some of these timbers in the base show evidence of reuse). An octagonal central mast is mounted on the principal joist (now bolted from below), and a circular ring plate 6×10in (150×200mm) is laid on the central square (in six pieces, joined from below with dovetailed keys), forming a base for a ring of curved braces rising to the rafters. The rafters are based on a circular plate around the top of the wall, and they rise to join the mast, and receive the braces at or above mid-height. There are eight principal rafters and braces, and four common ones between them. The remarkable feature of the design is that the braces curve upwards and outwards in an ogival (S-shaped) curve, while the rafters curve inwards and upwards in an ogival curve, making for some extraordinarily shaped spaces (Fig 35).

The North-West Turret

The floor below the roof is formed of a north-south joist and three common joists, with two more in the walls, and short pieces across the four corners (Fig 36). The joists are secured with diminished haunch tenons, some with extended shoulders scribed to the waney edges (Fig 37). The roof is based on a principal north-south joist and two east-west joists, with an octagonal central mast (secured from below with an iron bolt), eight straight braces up to a ring-purlin in eight sections, and downward braces to the cross beams to stabilise the mast (Fig 38).

The South-East Turret

This turret has a very fine interior of unspoilt medieval masonry, with Reigate quoins and ragstone rubble with galleted pointing (Fig 39). The 'ground' floor at the main roof level consists of a series of joists running east-west, which are jointed into edge beams with diminished haunches (Fig 40). Only the two outer joists and the east edge beam survive. There is a floor below the roof, with six east-west joists 5×7in (125×175mm) in cross-section, resting on bevelled timber plates 4in (100mm) deep let into the walls. At the west side of the floor, two of the joists are notched to allow a small opening only 14in (355mm) by 22in (560mm) to allow access to the upper level (Fig 41). Another significant feature of this floor is that the joists are not set level, but laid with a fall of approximately 3in (75mm) from one side of the turret to the other internally. Presumably the floorboards were covered with lead with an outlet drain on the east side of the turret, implying that the openings above were not weatherproof. The turret roof is based on a cross of two principal joists aligned north-south, with a central octagonal mast holding eight straight braces up to the rafters, and four downward braces to the cross beams (Fig 42).

The South-West Turret

The upper part of the turret is rebuilt in brick internally, with remains of a floor and two sets of cross-braces below the roof (Fig 43). The upper floor originally comprised six east-west joists 5½×8in (140×200mm) in cross-section, set at 16in (400mm) centres on a brick rebate, and looks possibly medieval. The fourth of these joists is missing, but evidence in the form of mortices for a lost trimmer on the joists either side show that it formed a trap opening against the west wall of the turret. However, from the edge of the missing trimmer there is only 9in (225mm) gap to the brick wall. There is evidence that the joists predate the insertion of the brickwork lining to the original stone walls, which made the trap too narrow and necessitated the removal of the trimmer and joist (Fig 44). And like the south-east turret, this floor also has a fall amounting to approximately 4½in (115mm) from the south to the north. It is almost inconceivable that the joists had decayed to the extent that they had settled this amount by the time the brickwork was inserted without any effort being made to level them. Instead, this raises the question of whether these joists were originally set with a fall to allow for a lead roof above, with a drain on the north side, to protect from wind-driven rain.

At the first landing level seen from the stair below is a pair of diagonally set cross-beams with iron ties (Fig 45). At a height of 22in (560mm) above the upper floor is another pair of braces, similarly laid corner to corner.

The roof is based on a cross beam (the principal joist runs north-south) with a central mast braced up to a ring purlin, and with downward bracing to the beams. As with the other roofs the mast is secured with a central iron bolt.

Objectives of Dating

The primary objective for dating was to obtain felling dates or date ranges for all major phases of construction, as well as for minor repairs. Among the specific objectives of the dendrochronology were:

- to attempt to find any primary phase timber-work and if possible some with evidence of sapwood to allow a felling date range to be calculated
- to investigate the bottom of the well and to attempt to date any timber-work found, to place in the correct historical context the construction of the well
- to date the medieval fittings such as doors to place in the chronological history of the White Tower
- to date the oak floorboards from the second floor found within the spine wall arcade
- to try to identify any timbers representing the documented 1530s repairs to the main roofs, specifically any replacement tiebeams
- to date the main roofs and through the comparison of precise felling dates ascertain if the east and west roofs are coeval, as well as the apse end of the Chapel roof
- to produce felling dates for the various floor structures within the White Tower and compare with any known documentary building accounts
- to date any suitable timber-work in the turrets and identify any sequence of repairs to the floors and roofs

Assessment

All of the accessible timbers were assessed for their suitability for dendrochronology. The first problem was that of safe access for sampling. Most of the rooms had ceilings 15–20ft (5–6m) high, and in many instances there were no floors, precluding access for both assessment and sampling until later on in the 1996-7 programme of works. Indeed, the main roofs were not fully accessible until 2005. The turrets also presented their own problems, in that many of the floors did not have boards, or the floor boards present were in a dangerous condition. This necessitated the laying of scaffold boards on each floor in turn. For this reason, assessment and sampling took place simultaneously.

The second problem was that of sampling whilst minimising the necessary interventions into the historic fabric. Whilst most of the structural timbers in the high ceiling beams and turrets could be cored conventionally and successfully plugged so as to minimise visible damage, this was not feasible for the doors and lintels. The two medieval doors in the basement had excellent dendrochronological potential, being generally constructed of riven boards with 100 to 200 growth rings. However, they could not be cored conventionally, nor could they be sectioned for obvious reasons. The end grain of the timber was too abraded or damaged to allow the rings to be accurately measured, and cleaning the surface would cause unacceptable visual damage to the timber-work. The faces of the timbers were generally covered in the patina of centuries, obscuring the rings, and again could not be disturbed. Alternative sampling methods would be required to access these ring patterns, as described under the Methodology section below.

There were a number of areas where drawbar socket linings may exist, but have been blocked historically, and unblocking these would have detrimentally affected the character of the surrounding stonework. This includes the doorway from the eastern basement room to the apsidal basement room, the northern doorway through the spine wall at ground floor level, as well as the upper eastern drawbar socket at the south entrance, and the door between the Chapel of St John and the eastern room at first floor level. In addition, some fragments of shuttering boards were noted in the vaults above the southern passage through the spine wall at ground floor level. However, to sample these would cause unacceptable damage to the fabric of a Scheduled Ancient Monument.

What little Norman material survived tended to be fragmentary, and in some instances desiccated to the point of fragmenting into small pieces. However, this material generally had good ring counts, having originated from slow-growing trees. The boards were almost always riven, again maximising the potential for ring counts. However, an interesting anomaly is found in the first floor embrasure cupboard lintels. Those on the east side of the building are all of riven boards with good ring potential, but were generally in poor structural condition, whereas those on the west side were converted tangentially ‘through and through’ although there was no clear evidence of their having been sawn. This reduced the dating potential of the western lintels due to the manner of conversion.

The timbers in the bottom of the well were also assessed. These were found to be of beech (*Fagus sylvatica*), and in riven plank form. These retained substantial number of rings, but the surviving planks still supported the stone well shaft, and for obvious reasons could not generally be sampled. However, a number of *ex situ* fragments were found in the mud at the bottom of the well shaft. None of the beech samples retained any evidence of bark edge, therefore it was vital that as many samples as possible be obtained to see whether the last measured ring dates might cluster, suggesting minimal removal of outermost rings.

The late-medieval roofs were constructed out of exceptional timber with outstanding dendrochronological potential, most of the trees being between 150 and 200 years old when felled. The only disappointing feature of these roofs was the equally exceptional thoroughness of the defrassing of the sapwood which took place during the twentieth century restoration. Not content with removing the sapwood edges, the very surface of the timbers were removed to give what was considered by some a ‘tidy appearance’. Only the roof timbers above the chapel escaped this indignity.

The repairs effected by Henry VIII were mainly limited to the Flamsteed Turret, where the main problem was that the forest of timbers was so thick it was not physically possible to fit in between the radiating curved braces of the onion-shaped dome. Many of the timbers used in the sixteenth-century construction of this structure were very fast grown and therefore intrinsically unsuitable for tree-ring analysis – in many cases having fewer than 40 or 50 rings. Documented repairs to the main roofs also appeared to use timber which was very fast grown, with many of the purlins at the north end of the roofs having fewer than 30 rings. For this reason it was not possible to confirm through dendrochronology whether these were in fact repair timbers from the 1530s.

Stylistically, the structures of the floors below were generally of Elizabethan or Georgian date, and were often of faster-grown timber, although a certain percentage of timbers among the large number available had enough rings to warrant sampling. Many of these timbers retained bark edge. The timbers associated with the 1730s insertion of the vaults tended to be faster-grown still, with few being suitable for analysis. Many of these were also of pine.

The turrets had been substantially repaired in the late eighteenth century, and whilst many of the timbers retained bark edge, many of these had 50 rings or fewer. Due to the paucity of good ring counts, some of these were sampled in the hope that they might cross-matched strongly between themselves.

Sampling strategy

The primary objective in sampling was to obtain complete sapwood wherever possible. This was especially important where phases of repair or alterations may vary by one or two years. In addition, it was important to have a good number of complete sapwood samples in order to identify stockpiled timbers and so to avoid suggesting a construction period which might be too early.

It was also important to obtain at least 10 or 15 samples from each phase of construction to allow a well-replicated chronology to be produced: timbers with good ring counts and only the heartwood/ sapwood boundaries surviving could be selected on this basis.

None of the earliest surviving timbers comprising the primary Norman construction phase retained any sapwood; indeed, even clear heartwood/sapwood boundaries were rare. Most of the samples from the south entrance drawbar socket were very fragmentary, and it was not possible to clearly provenance the fragments into individual boards. Similarly, one of the gutter linings from the western roof drains was broken into many small fragments, and all were analysed to give the best chance of them cross-matching to enable a longer sequence to be constructed.

Many of the fragmentary samples had fewer than the generally accepted minimum ring counts. Usually these would be rejected, but here, due to the national importance of the site, and because of the clear provenance and duplication of coeval samples, cross-matching was attempted. Both with the dry wood fragments as well as the waterlogged well timbers, it was desirable to obtain as many samples as possible, due to the absence of sapwood or bark edge. Only through the clustering of a large number of last measured ring dates can felling periods be predicted, as for example with the medieval ceiling boards at Peterborough Cathedral (Groves 2000a and 2000b) and at Bowhill (Groves 2002).

The vertical boards from the door between the eastern basement and apsidal basement rooms were sampled in two locations, one towards the top of the door and the other near the bottom. This was for two reasons – firstly to allow the second core to provide sufficient overlap should the first one fracture during drilling, and secondly to counteract grain drift and give the best chance of obtaining the outermost heartwood ring date. This was especially important given the absence of any heartwood/sapwood boundaries on the boards.

Most of the sampling was undertaken during 1997 and 1998. However, the number of samples taken from the main roofs was woefully inadequate for a structure of this size and importance. Therefore, further sampling of all three main roofs was commissioned by English Heritage during 2005.

Methodology

Sample Extraction, Processing, and Analysis

All samples were taken from what appeared to be primary first-use oak (*Quercus* spp.) timbers, or similar timbers reused, with reasonably long ring sequences, or with some indication of sapwood. All *in situ* timbers were sampled using a 16mm hollow coring bit, with the exception of the thin boards. Multiple samples were taken of many of the timbers, in order to obtain complete sapwood. Due to the protracted nature of sampling, which needed to be scheduled around the building works, the samples were taken in no particular order and were temporarily numbered with the prefix **tol**. Once the analysis was completed, the samples were renumbered chronologically with the new prefix **wt**, progressing through the building from the basement upwards. Details of the samples taken, together with dates produced, are shown in Table 1, and located on the drawings in Figures 46–52. Section drawings of all timbers sampled are shown in Figure 53.

For the door planks which were too thin to be cored conventionally, a micro-borer was used to extract the samples. This system was developed specifically for work on the White Tower doors. This is accomplished by using a small 8mm outside diameter hollow drill bit which extracts a 5mm diameter core. The drill bit is cooled and cleared of dust with the aid of compressed air which is channelled through the inside of the cutting tube and clears the waste from around the outside of the bit. By mounting the drill in a travelling carriage mounted on a large press or bench and accurately aligned to the surface of the timber, the drill can be used to bore through a number of boards as thin as 15mm thick and as wide as 750mm or longer. Thus a number of boards can be drilled in succession with the need to make only a single hole. A drill press was used to drill the door, and a series of rod guides of drilling the *in situ* drawbar socket on the ground floor spine wall. The cores thus extracted were mounted on grooved timber mounts and prepared in the same manner as the larger core samples.

Some timbers, such as the eastern niche lintels on the first floor, were too decayed to allow sampling even with the micro-borer. Here large-format black-and-white photographs were taken by Dr John Crook of the underside of the timber planks after lightly brushing, and these were printed out at 1:1 scale, mounted on card and measured under the microscope. Only one of the timbers was clean enough to allow the rings to be clearly distinguished.

The samples were sanded on a linisher using 60 to 1200 grit abrasive paper, and were cleaned with compressed air, to allow the ring boundaries to be clearly distinguished. They were then measured under a ×10/×30 microscope using a travelling stage electronically displaying displacement to a precision of 0.001mm, rounded to the nearest 0.01mm.

The waterlogged beech timbers from the well were of necessity processed differently. After sampling and assessment, each timber was wrapped in two layers of plastic with inner and outer labels, and taped. All timbers offcuts were considered artefacts, and were returned to the Curator of the Tower for long term storage and conservation. The samples were processed using standard dendrochronological techniques (Baillie 1982), which included freezing the samples after sectioning to a thickness of 25–50mm. Once frozen, the surface of the timber was prepared using a combination of smoothing plane and paring chisel to expose multiple radii, especially for narrow-ringed samples. These were then measured and compared with each other to confirm that there were no missing rings within the sample.

After measurement, the ring-width series for each sample was plotted as a graph of width against year on log-linear graph paper. The graphs of each of the samples in the phase under study were then compared visually at the positions indicated by the computer matching and, if found satisfactory and consistent, were averaged to form a mean curve for the site or phase. These mean curves, together with the individual ring sequences, were then compared against dated reference chronologies to obtain an absolute calendar date for each sequence.

In comparing one sequence or site sequence against another, *t*-values over 3.5 are considered significant, although in reality it is common to find *t*-values of 4 and 5 which are demonstrably spurious because more than one matching position is indicated. For this reason, dendrochronologists prefer to see some *t*-values of 5, 6, and higher, and for these to be well replicated from different, independent chronologies and with local and regional chronologies well represented. Where two individual sequences match with a *t*-value of 10 or above, and visually exhibit exceptionally close ring patterns, they most likely came from the same parent tree. Potential same-tree matches can sometimes be confirmed through the external characteristics of the timber itself, such as knots and shake patterns. An exception to this methodology is in comparisons between the massive tiebeams from the main roofs, many exceeding 43ft (13.1m) in length. Many of these had matches exceeding *t*=10, but clearly it was impossible for these to have originated from the same tree. Their sequences were therefore not combined. However, these timbers must have originated from the same woodland, which would account for the higher-than-average matches. For shorter ring sequences from the same tree, lower *t*-values are often encountered (English Heritage 1998).

Dating was accomplished by using a combination of visual matching and a process of qualified statistical comparison by computer. The tree-ring curves were first matched visually, and then independently matched by computer. The ring-width series were compared on an IBM-compatible computer for statistical cross-matching using a variant of the Belfast CROS program (Baillie and Pilcher 1973). A version of this and other programs were written in BASIC by D Haddon-Reece, and rewritten in Microsoft Visual Basic by M R Allwright and P A Parker.

A methodical approach is taken in dealing with the individual samples. Firstly, all duplicate radii from a single timber are cross-matched and compared, and if the matches are satisfactory, they are combined to form a single-timber mean. These multiple radii are generally identified by using an '**a**', '**b**', etc after the timber sample number. Cores which have broken into one or more segments are further identified by a '**1**', '**2**' after the radius suffix. Once a single mean sequence for each timber has been produced, the next step in the analysis is to check for same-tree matches. Again, all samples clearly identified as having originated from the same parent tree are combined to form a mean sequence for each tree. It is not until this preliminary analysis stage is completed that individual samples / trees are then compared with others from the site and combined into larger site masters.

All individual sequences and components of same-timber means and same-tree means are presented in Table 1. Because this is the primary summary of all material on which the dendrochronological analysis has been based, both actual samples and averaged sequences are presented here. The means of individual radii, as well as same-tree means, are differentiated in the table by the use of italic text. To avoid confusion, felling seasons and dates, or date ranges, are not presented in the final column for individual radii comprising a single timber. Instead, these are presented only for the mean of these individual sequences. Where two or more timbers have been found to originate from the same parent tree, each timber has been given a felling date or date range, but this would be the same as the mean sequence for the tree. Where one of the components making up a same-tree mean has complete sapwood, and another only partial or no sapwood, then the latter would be given the precise date in brackets, even though it would have only produced a *terminus post quem*, or at best a felling date range, on its own. Where all the individual same-tree components have incomplete sapwood, then a felling date range for the mean is produced by taking the average heartwood/sapwood boundary date, from which the appropriate 95% sapwood estimate is used to work out the felling date range. This range, in brackets, would then be used for the individual timbers comprising the mean. Similarly, where one or more radii or timbers making up a same-timber or same-tree mean have complete sapwood, the average sapwood ring count is presented for the mean.

Ascribing Felling Dates and Date Ranges

Once a tree-ring sequence has been firmly dated, a felling date, or date range, is ascribed where possible. With samples which have sapwood complete to the underside of, or including bark, this process is relatively straightforward and a *precise felling date and season* can be given. The latter depends on the completeness of the final ring, and whether it has only the spring vessels or early wood formed, or also includes the latewood or summer growth. If the sapwood is partially missing, or if only a heartwood/sapwood boundary survives, then only an *estimated felling date range* can be given for each sample. The number of sapwood rings can be estimated by using an empirically derived sapwood estimate with a given confidence limit. If no sapwood or heartwood/sapwood boundary survives, then the minimum number of sapwood rings from the appropriate regional sapwood estimate is added to the last measured ring to give a *terminus post quem* or *felled-after* date.

A recent review of the geographical distribution of dated sapwood data from historic building timbers has shown that a 95% range of 9–41 rings is appropriate for the southern part of England (Miles 1997). For Baltic imports, a range of 8–24 years is used (Tyers 2002).

It must be emphasised that dendrochronology can only date when a tree was felled, not when the timber was used to construct the structure under study. However, it was common practice in the Middle Ages to build timber-framed structures with green or unseasoned timber and construction usually took place within twelve months of felling (Miles 2005a). Given the protracted nature of the building campaign at the Tower, caution must be shown in interpreting construction dates, especially in subsequent phases of work, as has been shown in many cathedrals such as Lincoln (Laxton *et al* 2001), Exeter (Howard *et al* 2001), and Salisbury (Miles 2005b). However, a better interpretation of felling dates may be informed by complementary documentary evidence.

Cross-Matching and Site Chronologies

*Norman Well Beech Planks (*WHTOWR1*)*

When the well in the west basement was cleaned out sometime in the late nineteenth or early twentieth century, some timberwork was apparently observed at the bottom of the shaft. However, it was not until early 2005 that agreement was finally obtained to mount an extensive operation of draining the well and recording what sort of structure remained at the bottom. Four planks remained *in situ*, one was found *ex situ* but its position could be accurately determined, and three other *ex situ* fragments were found in the mud in the centre of the well. Only one of these could be sampled by sectioning a small V-cut near the end of one of the planks (**wt01**). Any further sampling would have weakened the structure, possibly causing future subsidence. However a number of *ex situ* fragments was recovered from the mud at the bottom of the well, and four of these were suitable for analysis (**wt02**–**wt05**).

All samples were cross-matched together as shown in Table 2, and their high degree of correlation showed that all planks originated from the same parent tree. They were combined to form a 176-year site master **WHTOWR1** (Table 3) which was then compared with a number of beech chronologies, both English and continental, and dated conclusively with a last measured ring date of AD 1081 (Table 4).

*Norman Phase Oak (*WHTOWR2*)*

A total of 21 fragments of timber board was recovered from various drawbar sockets in the basement and ground-floor levels of the White Tower (**wt06** to **wt14**). In addition, four micro-cores were taken from the intact lining in the ground-floor spine wall (**wt15** to **wt18**). Three samples (**wt06a**, **wt06b**, and **wt06c)** were from fragments all relating to the east side board, and were combined to form the mean **wt06**, as shown in Table 5. Those from the south entrance socket were very fragmentary and were over 10ft (3m) in from the face of the wall, so it was not possible to determine whether they formed part of the top, bottom, or sides of the lining box. Therefore, the fragments were all cross-matched together and those which were obviously from the same timber were combined. Thus, samples **wt08a**, **wt08b**, **wt08c**, and **wt08d** were combined to form the mean **wt08** (Table 6), **wt09a** and **wt09b** were combined to form the mean **wt09** (Table 7), **wt11a**, **wt11b**, and **wt11c** were combined to form the mean **wt11** (Table 8), **wt12a** and **wt12b** were combined to form the mean **wt12** (Table 7), and **wt14a** and **wt14b** were combined to form the mean **wt14** (Table 7). Together with the four micro-cores taken from the ground floor spine wall drawbar socket lining (**wt15** to **wt18**), all the ground-floor samples, with the exception of **wt10** and **wt13a**, **b**, and **c**, matched so well together that they were considered likely to have originated from the same parent tree. Therefore, they were combined to form the same-tree mean **wt0818** (Table 9).

Three embrasure lintels from the first floor were sampled – two from the north-western embrasure, which were cored with the micro-borer during conservation work, and one from the north-eastern embrasure, which was photographed. The samples from the south lintel of the north-west embrasure fragmented during sampling and were therefore sampled multiple times. Three cores, **wt19a**, **wt19b**, and **wt19c**, were found to match each other and combined to form the mean **wt19** as shown in Table 10. The cores from the opposite niche similarly fragmented, but one section, **wt20c**, with 39 rings, was found to match the mean **wt19** exceptionally well (Table 7). Together with similar physical characteristics, the two were considered to have originated from the same parent tree and were therefore combined to form the mean **wt1920**.

Two gutter linings were assessed and considered suitable for tree-ring analysis. Four fragments from the eastern mural passage were found to have originated from the same timber, and two samples, **wt22b** and **wt22d**, were combined to form the mean **wt22** (Table 7). One other segment, **wt22a**, was clearly from the same original board, but did not overlap with the other matching samples due to an area of decayed timber. This was therefore treated as an individual sample but included in the same master chronology as **wt22** because it was part of the same timber.

The second gutter lining analysed was from the western mural passage. This differed from the eastern one in that it was a timber hollowed out to form a channel into which lead was dressed. This timber was discovered in many small fragments, and the 11 with the most rings, ranging from 25 to 66, were cross-matched visually, taking into account their known physical relationships with adjoining fragments. Eight fragments were successfully matched together as shown in Table 11, and combined to form the mean **wt23** with 80 rings. Normally such short sequences would not be measured, but because of their known provenance in relation to each other and the clear visual similarities, it was decided to proceed with the analysis.

Once all the individual sample data were combined to form same-timber and same-tree means, these were cross-matched with the remaining individual samples. Seven sequences were found to match together with respectable *t*-values, as shown in Table 12.

These seven sequences were then combined to form the 277-year site master **WHTOWR2** (Table 13). This was compared to over 1300 local and regional reference chronologies and was dated to the period AD 816–1092 (Table 14). The matches were excellent with local and regional chronologies, suggesting that the timber originated from south-eastern England.

Two other samples did not match the other sequences, or the site master, but did date individually. Both were from the basement drawbar socket linings, and sample **wt06** with 83 rings dated, spanning the years AD 977–1059 (Table 15), and sample **wt07** with 104 rings dated, spanning the years AD 886–989 (Table 16). Only one timber sample, **wt13**, which had fragmented into three segments, failed to date.

*Edward III: Door to Basement Apsidal Room (***WHTOWR3***)*

Twenty-four samples were taken from 15 boards (**wt24–wt38**; Table 1) comprising the door leading from the east room to the apsidal room in the basement. All were taken using the micro-borer, and a number of the cores fragmented during the coring process. Subsidiary cores were taken from five boards to help reconcile these breakages, as well as help quantify the extent of the grain drift in the last measured outermost ring.

Firstly, all duplicate samples from the same boards were cross-matched and combined. Thus, samples **wt24a** and **wt24b** were combined to form the mean **wt24** (Table 7), **wt25a** and **wt25b** were combined to form the mean **wt25** (Table 7), **wt37a**, **wt37b1**, and **wt37b2** were combined to form the mean **wt37** (Table 17), and **wt38a** and **wt38b** were combined to form the mean **wt38** (Table 7).

Next, all individual samples or combined segments were compared with each other, and those matching consistently with *t*-values in excess of 10 were combined to form a same-tree mean (Table 18). Although this is not necessarily an absolute indicator of same-tree matches, especially with Baltic imports, it was decided to use the same methodology as employed elsewhere on this project. Therefore, four samples, **wt25**, **wt29**, **wt31**, and **wt37**, were combined to form the mean **wt2537**, which was used in the next stage of the analysis.

Thirteen sequences were found to match together as shown in Table 19. These were combined to form the 229-ring site master **WHTOWR3** (Table 20). This was compared with the reference chronologies from both Britain and Europe, and the best matches were had with Baltic chronologies, suggesting that the timber was imported from eastern Europe. The site master dated to the period AD 1109–1337 (Table 21).

Some of the very short fragments, such as **wt27a1**, could in this instance be reliably dated because a known amount of core was lost in drilling, and this could be converted to an estimated number of rings based on the mean ring widths of the two adjacent segments. The best match both visually and statistically corresponded very closely to the estimated number of rings lost.

*Edward IV: Door at the Bottom of the Great Vice (*WHTOWR4*)*

Seven samples were taken from six boards in this door, again through the use of the micro-borer. Two samples were taken from the first board as the first drilling hit an obstruction in the second board. Thus samples **wt39a** and **wt39b** were combined to form the mean **wt39** (Table 7). This matched with three other samples, **wt41**, **wt42**, and **wt44** (Table 22), and the four sequences were combined to form the 196-year site master **WHTOWR4** (Table 23). This, like the other door from the basement, matched best with Baltic reference chronologies, spanning the years AD 1245–1440 (Table 24).

The remaining two samples were matched with the site master but failed to match conclusively. They were then compared with the reference chronologies individually and whilst sample **wt43** failed to date, sample **wt40** did match conclusively at AD 1449 (Table 25). Whilst the matches here were not as strong as for the site master, they nevertheless were consistent.

*Henry VII: Main Roof Reconstruction (*WHTOWR5*)*

A total of 69 samples was taken from 46 timbers from the main roofs, second floor boards, and posts supporting the second floor structure (**wt45** to **wt90**). Duplicate samples were first combined to form same-timber means. Therefore samples **wt56a** and **wt56c** were combined to form the mean **wt56** (Table 7), **wt57a** and **wt57b** were combined to form the mean **wt57** (Table 7), **wt59a**, **wt59b1**, and **wt59b2** were combined to form the mean **wt59** (Table 26), **wt61a** and **wt61b1** were combined to form the mean **wt61** (Table 7), samples **wt71a2** and **wt71a3** were combined to form the mean **wt71** (Table 7), **wt73a**, **wt73b**, and **wt73c** were combined to form the mean **wt73** (Table 27), **wt74a**, **wt74b**, and **wt74c** were combined to form the mean **wt74** (Table 28), **wt76a** and **wt76b** were combined to form the mean **wt76** (Table 7), **wt78a1**, **wt78a2**, **wt78b1**, and **wt78b2** were combined to form the mean **wt78** (Table 29), **wt85a**, **wt85b**, **wt85c**, and **wt85d** were combined to form the mean **wt85** (Table 30), and **wt88a** and **wt88b** were combined to form the mean **wt88** (Table 7).

Next, same-tree matches were identified and the sequences combined. Normally individual timbers matching with *t*-values over 10 would be considered to have originated from the same tree. However here in the main roofs, some of the principal tiebeams, many of which are over 40ft (13m) in length and clearly represent entire trees, matched each other with outstanding *t*-values in excess of 12. Only the smaller subsidiary timbers, such as planks, purlins, and wall-plates, with consistently high matches over *t*=10 were combined to produce same-tree means. Therefore samples **wt49** and **wt55** were combined to form the mean **wt4955** (Table 7), **wt57a** and **wt57b** were combined to form the mean **wt57** (Table 7), **wt65** and **wt66** were combined to form the mean **wt656** (Table 7), and **wt70**, **wt75**, **wt81**, **wt85**, and **wt86** were combined to form the mean **wt7086** (Table 31). In this last group, sample **wt81** matched with lower *t*-values, but the similarity in the graphs supported the conclusion that it was from the same tree as the other four timbers.

All of these same-tree means together with the individual sample sequences were then compared together. This included material from the main roofs, the floorboards from the second floor below, and two posts supporting the second floor. Of the 46 individual timbers sampled, 43 were found to match together sufficiently well to combine into one master chronology (Table 32). Thus the 230-ring site master **WHTOWR5** was constructed (Table 33). This matched with outstanding matches with a variety of regional and site masters centring on London (Table 34), spanning the years AD 1260–1489.

Only three timbers failed to date: a couple of lower wall-plates (**wt54** and **wt80**) and a beam over the apse end of the chapel roof (**wt82**). These all had fewer than 100 rings and a mean ring width of generally more than 2mm, suggesting that they originated from different sources to the timbers included in **WHTOWR5**. It is quite possible that some of these may actually relate to the 1530s repairs, although without closer physical inspection it would be difficult to confirm this. These three samples were compared with the reference chronologies individually, but no consistent matches were found. They were also compared with the other 1530s repair material (see below) but again no conclusive, replicated, matches were noted.

*Henry VIII: Turret Roof Repairs (***WHTOWR6***)*

Twenty-three samples (**wt91**–**wt106**; Table 1) were taken from 16 timbers in the four turrets from repairs thought to be sixteenth century in date. All individual sequences were combined to form same-timber means. Therefore samples **wt92a** and **wt92b** were combined to form the mean **wt92** (Table 7), and **wt97a** and **wt97b** were combined to form the mean **wt97** (Table 7). One timber was cored twice but fractured along a decayed ring shake; two composites were therefore constructed: **wt99a1** and **wt99b1** from the inner part of the timber were combined to form the mean **wt99ab1** (Table 7), and **wt99a2** and **wt99b2** from the outer part of the timber were combined to form the mean **wt99ab2** (Table 7). Finally, samples **wt102a**, **wt102b**, and **wt102c** were combined to form the mean **wt102** (Table 35).

Two site masters were constructed. The first is composed of upper floor joists from the south-west turret. Firstly, samples **wt100** to **wt104** were combined to form the site master **wt1004** (Table 36). This composite had only 65 rings and failed to date. All samples were tried individually and with other site masters, but no conclusive matches were found.

Ten other samples cross-matched each other (Table 37) and were combined to form the second group, the 163-ring site master **WHTOWR6** (Table 38). This was compared with the reference chronologies and was found to date, spanning the years AD 1370–1532. The best matches were with chronologies located to the south and west of London (Table 39).

*Elizabeth I and James I: Internal Alterations and Repairs (***WHTOWR7***)*

A total of 29 samples was taken from 24 timbers (**wt107**–**wt130**; Table 1). As with the other groups of samples, individual samples were first combined to form same-timber means.

Thus samples **wt111a**, **wt111b**, and **wt111c** were combined to form the mean **wt111** (Table 40), **wt124a** and **wt124b** were combined to form the mean **wt124** (Table 7), and **wt129a** and **wt129b** were combined to form the mean **wt129** (Table 7).

Nineteen individual samples were found to match together as shown in Table 41, and were combined to form the 154-ring site master **WHTOWR7** (Table 42). This dated exceptionally well, spanning the years AD 1463–1616 (Table 43). As can been seen in the geographical spread of the regional master chronologies with which they were matched, the timber seems to have originated in south-east England.

George II: Reconstruction of Basement Vaults (WHTOWR8)

Ten samples were taken from seven timbers above the basement vaults in the eastern chamber at ground-floor level (**wt131–wt137**; Table 1). Samples **wt133a** and **wt133b** were combined to form the mean **wt133** (Table 7), **wt135a** and **wt135b** were combined to form the mean **wt135** (Table 7), and **wt136a** and **wt136b** were combined to form the mean **wt136** (Table 7).

Six of the seven timbers were found to match together as shown in Table 44. As will be noted, the cross-matching is not as strong as in earlier site masters. This is most likely due to the timbers being obtained from diverse sources, which is typical of eighteenth-century London.

These six timbers were combined to form the 88-ring site master **WHTOWR8** (Table 45). This was compared with the master chronologies and was found to date, spanning the years AD 1645–1732 (Table 46). It will be noted that the best matches were found to the west of London, supporting evidence for the timber trade along the Thames.

George III: Turret Repairs (WHTOWR9)

A total of 26 samples was taken from 18 timbers from the turret roofs and upper floors (**wt138–wt155**; Table 1). Duplicate cores were combined first. Samples **wt139a**, **wt139b**, and **wt139c** were combined to form the mean **wt139** (Table 47), **wt145a** and **wt145b** were combined to form the mean **wt145** (Table 7), and **wt148a** and **wt148b** were combined to form the mean **wt148** (Table 7).

Fourteen of the 18 timbers were found to match together, as shown in Table 48. These were combined to form the 154-ring site master **WHTOWR9** (Table 49). This was compared with the master chronologies and was found to date, spanning the years AD 1629–1782 (Table 50). As in the early eighteenth century timbers, a predominance of matches with western chronologies would suggest that these timbers were brought down the Thames to the flourishing London timber trade.

Interpretation and Discussion

Norman Phase

A large number of primary-phase Norman timbers were ultimately sampled. However, it was not surprising that no sapwood survived, and given that most of the timbers sampled were boards, very few heartwood/sapwood transitions were evident. A fragment from the basement drawbar socket produced a *terminus post quem* or felled-after date of AD 1068, and one sample from the ground floor with heartwood/sapwood boundary producing a felling date range of AD 1049–81. Slightly later, and straddling the known building break of *c* 1090, were two lintels from the first-floor embrasure cupboard recesses. These gave felling date ranges of AD 1055–87 and AD 1072–1104 respectively. The latest-ending sample was found in the roof drains on the east side, with one timber giving a last measured ring date of AD 1092, consistent with a felling date of after AD 1102 (Fig 54).

Of the five samples taken from the well, all samples were cross-matched together, and their high degree of correlation showed that all planks originated from the same parent tree. They were combined to form a 176-year site master that was then compared with a number of beech chronologies, both English and continental, and dated conclusively with a last measured ring of AD 1081. The best matches were with the London beech chronologies constructed by Ian Tyers (*in prep*). None of the samples retained bark edge, and as beech does not have discernible sapwood, it is not possible to determine how many rings might be missing from the outside edge of the planks.

Therefore only a *terminus post quem* date of AD 1082 can be given. However, four of the samples extended to the squared edge of the planks, with the last measured ring dates ranging from AD 1070 to 1081. Given the closeness of these last measured ring dates, it is unlikely that more than five or ten rings were removed from the boards on preparation, making the actual felling date not much later than AD 1082 (Fig 54).

The traditional construction period for the White Tower commencing in 1078 has been drawn from the *Textus Roffensis* (Hearne 1720). Gundulf was appointed Bishop of Rochester on the 19 March 1077 and at this time he was recorded as supervising the work on the great tower of London. However, there is nothing specific in the *Textus Roffensis* to say that Gundulf began the works, or that they were in progress when he was made bishop, and that construction could have been started anytime between 1077 and 1087 when William the Conqueror died (Roland Harris pers comm). A charter dated 1097 suggests that work was still in progress on the castle, although nothing specifically relates to whether the White Tower was actually completed at the time (Gibbs 1939, 15; Harris pers comm). However, the famous 1101 escape after a feast by Rannulf Flambard by climbing down a rope from an upper window as documented in the *Anglo-Saxon Chronicle* suggests that the building was effectively complete by this time (Harris pers comm).

The tree-ring dates produced in this study confirm that various elements are indeed Norman in date, and support the traditional construction dates for the Tower. However, without complete sapwood, the broad felling date ranges produced cover much of the known construction period, and even if bark edge did survive, the likelihood of stockpiling would have made interpretation difficult. Nevertheless, the *terminus post quem* date of AD 1068 from a basement drawbar socket lining scientifically proves that the White Tower did not commence construction until after this date.

More useful are the felling date ranges produced by the first floor niche lintels. The western lintels are stratigraphically thought to belong to the pre *c* 1090 building break, and would have been laid into place during the last season of construction. The felling date range of AD 1055–87 for two of these suggests, even with the possibility of stockpiling, that an AD 1087 could be considered a *terminus ante quem* for the building break. On the other hand, the dated eastern lintel is placed immediately above the building break, and would have been one the first pieces of timber to be laid on the recommencement of the mason's work. Although the AD 1072–1104 felling date range is perhaps less useful in that it straddles the construction break, the fact that this second felling date range is significantly later than those for the western lintels supports the hypothesis that it dates from after the construction break.

Similarly, the *terminus post quem* date of AD 1082 for the beech well timbers would suggest that this feature was constructed either at the very end of 1080s, or shortly after the construction break in the early 1090s. The use of mortar typical of the post-construction break masonry would suggest that the early 1090s is more likely than the previous decade. This is especially important in showing that the well was not dug until the tower had at least advanced to above first floor level and was not the earliest part of the keep to be constructed.

Finally, the *terminus post quem* date of AD 1102 for a gutter board would suggest that this would be the earliest that the Tower was completed. This presents a slight problem in relation to the traditional completion of the Tower by no later than 1101. The gutter would have been a fundamental part of the roof, and is unlikely to have been completed afterwards. However, given that the eastern drain timber is a simple board, as opposed to the hollowed out formers used in the western drains, perhaps this was an early modification to improve drainage from the gutters.

Door I: Edward III

As for later medieval fittings, the earliest is the door at the end of the east basement room into the apsidal room. Of the 15 boards sampled, 14 dated. As four of the boards were thought to have originated from the same tree, the dated boards were considered to have originated from 11 individual trees. As none of the boards retained any evidence of a heartwood/sapwood transition, only *termini post quem* or felled-after dates could be offered. The latest board had a last measured ring date of AD 1337, indicating a *terminus post quem* of AD 1345 for this group. However, given the tight clustering of dates, and the assumption that a minimal number of heartwood rings was removed along with the sapwood (Miles 2005a), a date of *c* 1350 might be offered for this door in the interests of simplicity (Fig 55). This corresponds to a period of busy activity in the tower at the commencement of its role as an ordnance store during Edward III's French wars. The character of the carpentry is appropriate for this date, with less of the sophistication than might be expected at an earlier date, while the use of Baltic timber demonstrates the preferred choice of imported boards for quality joinery (Simpson and Litton 1996).

Door II: Edward IV

The door to the bottom of the Great Vice in the Flamsteed Tower produced only six samples, as opposed to the 14 boards sampled from the door at the south end of the east basement room. Here the latest measured ring dates of the five dated boards were not as consistent, but some sapwood was noted further up on board 3 (**wt41**), so its last measured ring date of AD 1432 is not far off the heartwood/sapwood boundary (Fig 56). Together with the *terminus post quem* of AD 1457 for sample **wt40**, a construction date of *c* 1475, during the reign of Edward IV, may be suggested. Although the door could have been constructed as late as 1490 when the main roofs were replaced, it is unlikely that more than 40 heartwood rings were removed with the sapwood (Miles 2005a). There are no known building works during these periods which might place in context the replacement of this door. Again the timber used in the construction of this door was found to have been imported from the Baltic area.

Main Roofs: Henry VII

Of the 46 timbers sampled in the three main roofs and the second floor structure below, 43 produced tree-ring dates. However, due to the ravages of the twentieth-century restoration, only nine precise felling dates were derived. Five of these timbers were found to be felled in the spring of AD 1490, one in the winter of AD 1489/90, two others in the spring of AD 1489, and one in the spring AD 1488. The remaining timbers with incomplete sapwood produced estimated felling date ranges consistent with these precise dates (Fig 56).

Despite the paucity of bark edge, the distribution of the latest precise felling dates of spring AD 1490 between the western roof and the roof over the chapel suggests that these two roofs would have commenced construction during 1490. This is supported by the similarity in carpenter's assembly marks between the roofs. The dating of a common rafter from the apse end of the chapel roof to spring AD 1490 confirms that this is part of the same phase.

It is through likely same-tree matches that we are able to further interpret the parts of the structure lacking precise felling dates. For instance, the ridge beam from bay 4 in the east chamber roof, the ridge beam from bay 2, the large jowelled post under truss IIII in the chapel roof, and two planks used in flooring the second floor were considered to have originated from the same parent tree (Table 31). None of these five timbers retained complete sapwood, so a felling date range of AD 1486–1509 was ascribed to all of them. However, the same-tree matching demonstrates that the east chamber roof and the second-floor boards are constructed using the same consignment of timber as that used in the chapel roof, and are thus likely to be coeval with the precise felling dates of spring AD 1489 to spring AD 1490 found for associated timbers in the chapel roof. The floor planks are tangentially-sawn, 2in (51mm) thick, with widths varying between 12in and 15in (305–381mm), and were fixed with large wrought-iron spikes.

The two first-floor posts sampled under the second floor east chamber lacked any heartwood/sapwood transitions, but did have last measured ring dates of AD 1407 and AD 1448, giving *termini post quem* of after AD 1416 and AD 1457 respectively. It is quite possible that these too related to the insertion of the second floor in 1490, and this theory is given weight by their good cross-matching with the roof timbers, suggesting that they at least originated from a similar source.

There is no immediately recognisable historical context for this work. It is thought that the upper room of the White Tower was used by the Knights of the Bath for their ritual washing on the night prior to the Coronation, but the date of the roof cannot be related to a coronation. Henry VII had been crowned in 1485 before he was married, and indeed Elizabeth of York had to wait until after the birth of her first child for her separate coronation in November 1487, on which occasion she travelled by barge to the Tower and returned through the city in a litter, following the protocol used for Richard III's coronation; neither of these events can have been the cause.

One of the objectives of the dendrochronology programme was to try to identify the 1530s repairs, but apart from northern tiebeam in the west room, and the two northern tiebeams in the east room, all of which were replaced in the mid-twentieth century, all principal beams were found to relate to the 1490s roof, as were all the purlins and rafters sampled. However, the purlins in the northern bay of both the east and west rooms were markedly different in character, being converted from whole, very fast-grown trees, in contrast to the 1490s purlins which were from large, very slow-grown trees, cut into quarters. It is also possible that one or two of the three tiebeams replaced in the twentieth century were 1530s replacements.

One important result of the tree-ring dating was the confimation of the southern-most ridge beam and tiebeam in the western roof (**wt62** and **wt63**), which produced felling date ranges of AD 1477–1505 and AD 1479–1511 respectively. These timbers are important in that the tiebeam retains evidence for some sort of decorative timber facing akin to a reredos but in a secular context. Given that the dated ridge beam was also decorated with chevron patterns in tacks, the dendrochronology has here proved that the south end of the western room was decorated when the roofs were constructed in 1490, as the southern row of studs were pegged from the south, before the stone wall was built up adjacent. Although the use of this end of the room at this time is not clear, these investigations have made an important contribution to the understanding of the function of the White Tower at the end of the fifteenth century. It is unfortunate that no supporting documentary information could be uncovered to accompany this most major alteration to the building.

Henry VIII

Although dendrochronology failed to identify any of the documented 1530s repairs to the main roofs, some were found in the turrets. Sixteen timbers were sampled from elements found to date from these repairs, including replacement floors in the south-east and south-west turrets, and the roof of the Flamsteed Tower. Two floors in the south-east turret were sampled – the first-level floor at main roof level, and the third-level floor. Although none of the timbers from the third-level floor dated, a main beam and a common joist dated at the first-level floor. The joist retained complete sapwood, and was found to date to the spring of AD 1532. The adjacent beam gave a felling date range of AD 1522–54, consistent with the date of the joist. Two samples from the corresponding third-level floor joists in the south-west turret dated, one producing a felling date range of AD 1503–35, and the other a *terminus post quem* of AD 1515. Given the stylistic similarities between the third-level floors in both turrets, it is likely that the undated joists in the south-east turret probably date to the same building campaign (Fig 57).

In the Flamsteed Tower, three samples from the ogee braces and upper ribs produced precise felling dates of winter AD 1531/2, spring AD 1532, and spring AD 1533. Three other timbers with incomplete sapwood gave felling date ranges consistent with these precise felling dates (Fig 57).

The context of the 1530s work is interesting, for it again points to a state occasion when the Tower was repaired, this time the coronation of Anne Boleyn in 1533. The works accounts refer to the carpenters removing '*the olde tymber upon the iiij turretts upon the White Tower*', and plumbers covering the four turrets '*being half fynnysshed*' (TNA E101/474/12). This and the following year's account have many references to the '*four Types'* on the White Tower, which may mean that the turrets were themselves finished with heraldic beasts, though the references to roughcast brickwork suggests that they were set on their own brick piers. There is a separate reference to the north-east turret in the account of works (probably) before January 1533: '*Item a flower made and redy framed for the Rownde Tower on the White Tower whiche is not yet sett up*' (TNA E101/474/13). Clearly the roof frame was not quite ready in 1533, as one of the rafters was still growing in the woods that spring.

It must have been at this time that all the turrets achieved their fashionable ogival profile, in what Fletcher noted as the ogival revival around 1500, exemplified by structures such as the bell turret on the Curfew Tower at Windsor Castle, and royal palaces at Richmond, Greenwich, and Hampton Court. Although the other turrets were repaired in the later eighteenth century, the Flamsteed Tower dating points to the date of origin as the 1533 coronation of Anne Boleyn (Colvin *et al* 1975, 265). The appearance of the White Tower with four new and decorative turrets, and the four heraldic Types, must have been splendid. The newly repaired battlements were not altogether without purpose, however, and in January 1534 Chapuys reported to the Emperor that the King had placed guns on the top of the Tower commanding the city (*L & P Henry VIII*). When required it could still function as a fortress.

Elizabeth I

It is not until we reach the reign of Queen Elizabeth I that we are able to reconcile the tree-ring dates with complementary documentary accounts. Two phases of Elizabethan work have been identified (Fig 57).

The first relates to the first-floor columns (ie those supporting the second floor) in the eastern division, of which one (**wt107**) was felled in winter AD 1565/6, as well as the two with *termini post quem* in the fifteenth century discussed above. The sixteenth-century post fits well with a recorded series of works in the 1560s. The accounts for 1565–67 include '*making a newe office for the recordes, making framing and finyshing twoe newe Armouries in the White Tower*' (TNA E351/3203). This was not necessarily the occasion when all the work was done, for in July 1568 there was discussion of how the Queen could be persuaded to spend money on the *'great Tower*' for the preservation of her armour and records '*which taketh hurte daylie*', and what materials would be needed, which included 600 trees for this and other work (*Cal S P Dom Eliz 1547–90*). The following May there was some delay in obtaining the Queen's approval, while '*tymber reddie framed for Westm and the Tower*' awaited carriage (British Library, Lansdowne MS XI). In June 1569 the Surveyor Lewes Stockett was ordered to finish the '*works beguon at the Exchequior, the Recordes & other Romes of Tharmory within the Tower of London*', though he had still not received full payment in 1570 (*Cal S P Dom Eliz, Addenda 1566–79*).

The second phase of repairs relates to work carried out at the very end of Elizabeth's reign. Eleven of the 20 samples taken from the columns of the western division of the ground floor (supporting the first floor), and the columns and ceiling joists on the first floor (supporting the second floor), produced precise felling dates. These ranged between summer AD 1602 and spring AD 1603. Queen Elizabeth died in March 1603, and preparations were made for King James's coronation, in particular in the Knight's bathroom in the White Tower, although in the event this took place in St James's Palace and not the Tower of London. The accounts include: '*layinge the newe planckes in Cesars hall in the Tower plaine one by another against the kinges Majestie comeinge for the knights of the Bath all over the olde broken flooores*'….. '*Plasterers… platforeing the wall of Casars hall for the knights of the Bathe againste the Coronacon*' (TNA E351/3238). This has rather a makeshift ring to it, and is hardly consistent with the wholesale refitting that must have happened.

There is better evidence for large-scale construction in the following years in association with the new Powder House that was being constructed in the basement. In the Works accounts for 1603–4 are more detailed description of the operations (TNA E351/3239):

> *framinge of Joystes and Brest Sommers for the newe flower of the powderhouse in the white Tower, liftinge straight of planckes which have been sawen twoe yeares for the same flower, and the next oulde flower under it... sommers of the new flower that is making in the white Tower for the new powderhowse helping the Labourers to crane up tymber out of the bardge at the wharf and loading the cartes with it that carried up into the Tower to the Sawpitt, Craning up the framed tymber, framing and raysing of the Carpenters woorke of the postes plates ioystes and breast sommers for the newe flower made in the white tower for the powder house, Craning up the frames tymber framing and leauelling the ioystes upon the walles of either side of the flower, raising the breast sommers and the longe binding ioystes, lifting straight of planckes putting in and leuelling the ioystes for the newe flower, which is making all the length of the great white Tower for the newe powder house*

And this continued into the next year of the Works Acccounts, for 1604–5 (TNA E351/3240):

> *joisting and planckinge of the greate floore in white Tower for a powder house there puttinge in of sondrie newe joists in the middle floore under the newe floore Liftinge straighte of planckes and newe planckinge of the same flower in manie places, puttinge in*

of newe plates uppon the walls to beare the endes of the joists cuttinge out and takeinge downe some of the uprighte posts in the upper story of the white Tower which did beare the roofe and were all rotten and decaied woorkinge and ymbowinge of newe posts to sett in their place proppinge and Screwing upp the maine beames and principall tymber of the roof of white Tower whilest the olde were taken out to put newe in their place frameinge in the newe posts and plate into the beames and braces of the roofe puttinge in of peces of Tymber on the backside of the other uprighte postes which stood besides the wall againste the windowes for the strengthininge of them and boultinge them together with greate yron boultes puttinge in of some new joiste uppon the toppe of the roofe under the leades and planckinge the same with newe plancks, puttinge in quarters under the Recordes offyce and of tymber betwene the Joists overhead where the spaces were too wyde to lathe unto frameinge together twoe blocks of tymber to clippe the foote of the uprighte piller in the lowe darke sellor under the recordes...

The comparisons between the tree-ring dates of AD 1602 and AD 1603 compared with the contemporary documents illustrate the importance of such research. The documents show that the programme of work in reconstructing the western floors extended over several years, being completed in about 1605.

James I

Three timbers were sampled from the floors within the south-west turret. At the first landing level, as seen from the stair below, one of a pair of diagonally set cross-beams with iron ties dated to the winter AD 1616/17. Two other cross-braces set above the top floor gave felling date ranges of AD 1607–39 and AD 1617–39, and are clearly contemporary with the winter AD 1616/17 date from below (Fig 57).

This work is undoubtably contemporary with the internal brick lining and probably relates to an account dating from 1 October 1618 to 30 October 1619 which says: '…*John Andrrews Bricklayer for bringing up with bricke and paving with bricke an edge with Tarris xxxvi loope holes betwene the battlements on the Toppe of the white Tower… xxx s'* (TNA E351/3252). That this work also related to the internal works to the south-west turret is found in a survey of the Tower dated 31 December 1623 which says '…*Two of thos Turrets towards the Thames are roughe case verie Seemely and whereby the walls (formerly Ruyned) are nowe preserved…*' (TNA SP14/156). This would suggest that the two southern turrets had been repaired between 1617 and the end of 1623.

George II

During the first half of the eighteenth century the main area of work to the White Tower was the insertion of brick vaults in the basement, and some replacement of the timberwork above at ground floor level. Three floor beams, a joist, and three posts were sampled, and all but one dated. Of these, four were precise felling dates, three being winter AD 1732/3 and one from the spring of AD 1733. The remaining two dated timbers produced felling date ranges of AD 1719–51 and AD 1723–55, entirely consistent with the precise felling dates already obtained (Fig 58).

These tree-ring dates tie in nicely with documented works during the second and third quarters of 1732, including an item for '*digging the foundations for the brick peers in the salt petre room*' (TNA WO 51/129/127v), and another for Sir William Ogbourne, carpenter, for '*Taking down the floors, shoering the flat making setting and striking centers for the vault, sorting and cutting the old timber for giles etc…*' (TNA WO 51/128/73v). Similar works the following year during the first to third quarters of 1733 include '*Levelling and assisting the carpenters to settle the centres in the White Tower…*' (TNA WO 51/132/21r) and for Sir

William Ogbourne for '*laying the third floor, shoring and securing the flatt, making a new ceiling floor and bridging the old floor for boarding, making a scaffold for the plasterer and setting up the old posts*' (TNA WO 51/135/25r). In the first quarter of 1734, Ogbourne was '*compleating the east side by taking down the old floors, shoaring and securing the roof, converting old timber into joists, corbels etc, framing and raising the floors with old and new timber, boarding the floors and fixing up storey posts in each floor….*' (TNA WO 51/132/91r).

This last entry is significant in understanding the upper floors, in that it would appear that they were largely dismantled at the time the vaults were constructed at basement level, and that they were subsequently reconstructed, using many of the original timber posts and beams. Thus the fifteenth-century posts and the AD 1565/6 post referred to above are not likely to be in their original positions.

George III

The last major works identifed through the dendrochronology programme were repairs to the four turrets. Eighteen timbers were sampled in the four turrets, and all but four of these dated, with precise felling dates being derived for 13 timbers. These showed a progression of repair starting from the south-west with a latest felling date of winter AD 1779/80, then to the north-west turret with winter AD 1780/81, the south-east turret with spring AD 1781, and finally to the Flamsteed Tower with the latest felling dates of spring AD 1783 (Fig 58). Some stockpiling was noted, with the earliest felling date of spring AD 1777 being over three years earlier than the latest felling date from the north-west turret.

There is some documentary evidence for this work, although this is somewhat sporadic, and sometimes does not specify which turret is being worked on. The first entry in the accounts, dated 31 December 1780, is for master carpenter James Morris, for erecting scaffolding on the turrets of the White Tower (TNA WO 51/300/160), with an identical entry exactly one year later. On 30 September 1781 there is an account from William Tyler, master mason, for repairing the turrets (TNA WO 51/300/99–100), and on 31 December of the same year there is an account from Richard Jourdan, plumber, for work on '*the second turrett of the White Tower*' (TNA WO 51/305/34v). This would probably relate to either the south-west or north-west turrets, as there would have only been about five months between the felling of the timber for the south-east turret and the leadwork being completed.

Further accounts at least specify which turret is being repaired, with one bill from 30 September 1782 from the plumber Richard Jourdan for '*completing the covering with new sheet lead, the south-east turret of the White Tower*' (TNA WO 51/302, 262, also 142r). The latest account dates from 31 December 1783, from the mason William Tyler, for work to the Flamsteed Tower (TNA WO 52/21/18r). These accounts support the progression suggested by the dendrochronology.

Conclusions

A total of 243 samples was taken from 155 individual timbers, representing 10 principal building phases or elements from the White Tower. The earliest of these is the primary Norman construction phase, of which no original timber was initially thought to have survived. However, sections of boards still *in situ* in a basement drawbar socket, and dislocated fragments in a drawbar socket in the south entrance, provided some material to work from. Then a socket in the spine wall of the ground floor was discovered behind some twentieth-century Ministry of Works blocking, and when opened up, a perfectly preserved timber socket lining was found. These timbers produced a latest *terminus post quem* or felled-after date of AD 1068 for the basement drawbar socket lining, and a felling date range of AD 1049–81 for the ground-floor drawbar socket lining.

The lintels to the niches to the embrasures on the first floor were studied, and a combination of micro-bores and photographs allowed a number of these to be dated, two giving felling date ranges of AD 1055–87 and AD 1072–1104 respectively. The final element of what was thought to be primary phase material was that discovered under the east and west mural passages on the top floor, interpreted as the rainwater drains to the original roof. On the west side, the lead was laid over U-shaped oak linings, one giving a *terminus post quem* of AD 1014, while on the east side a board was found giving a last measured ring date of AD 1092. As there was no evidence of sapwood, only a *terminus post quem* of AD 1102 could be given. Clearly this sample was not of the same phase as the lower drawbar socket linings, and although it was not possible to say how many growth rings were missing, experience has shown that often only a minimal amount of heartwood was removed. Nevertheless, it is possible that this board represents an early modification after the White Tower's traditional completion date of *c* 1100.

The final area of potentially primary Norman work to be investigated was found not at the top of the White Tower, but in the well deep below the basement floor. Five beech samples dated, with the best matches found with the London beech chronologies constructed by Ian Tyers. The latest sample produced a last measured ring of AD 1081, giving a *terminus post quem* of AD 1082. Given that the mortar used in the construction of the associated stonework is typical of the post-1090 construction break, the well is most likely to date from the early 1090s.

Progressing chronologically, the next phase of construction is the door at the south end of the eastern basement room. Here 11 micro-bore samples were dated, and although none of them retained any sapwood, the end dates were all so close together that it is likely that the minimum amount of heartwood was removed. A latest *terminus post quem* of AD 1345 for the group was determined, with felling likely sometime around the middle of the fourteenth century. The door to the bottom of the Great Vice in the Flamsteed Tower was similarly sampled, and although five boards dated, the alignment of the last heartwood dates were not as consistent, so one can only suggest that these might have been felled *c* 1475. The timber used in the construction of both doors was found to have been imported from the Baltic.

The main roofs to the whole of the White Tower were found to have been renewed shortly after 1490, as revealed by felling dates of spring AD 1489 and spring AD 1490. Although 40 samples were taken from of the main roofs, only eight precise felling dates were obtained, as virtually all of the sapwood had been removed from the timbers when the roofs were repaired in the 1960s. A ninth felling date from a floorboard under the spine wall arcade on the top floor produced a felling date of spring AD 1488, and two other floorboards were found to have been originated from the same trees as used in the main roofs, demonstrating that the top floor had been constructed at the same time.

Although no surviving timbers relating to the 1530s repairs to the main roofs were found, six samples from the ribs of the Flamsteed Tower dated, with some precise felling dates ranging from the winter of AD 1531/2 through to the spring of AD 1533. Four floor joists and a beam in the south-east turret also dated to this period, with one precise felling date of spring AD 1532.

The reconstruction of the western half of the White Tower at the transition between Elizabeth I and James I is revealed by a good assemblage of precise felling dates ranging from summer AD 1602 to spring AD 1603. The eastern half of the building has proved more enigmatic, however, with only one post on the first floor producing a felling date of winter AD 1565/6, the same year as the Royal Armouries first began using the building. Two other posts from this room produced sequences dating a century earlier. This may simply be because they lost their heartwood/sapwood boundaries along with a large number of heartwood rings, but more likely they may have been re-used from an earlier phase which is yet to be identified. Accounts from 1734 suggest that these posts and floors had been taken down and reconstructed, so it is unlikely that these timbers are *in situ*.

Later repair episodes have been identified through dendrochronology. An unknown phase of strengthening to the south-west turret was revealed by felling dates of winter AD 1616/17, and a study of contemporary bricklayer's accounts indicate the walls to the turret were repaired between October 1618 and October 1619. A more major change was the insertion of the brick vaults in the basement. This was confirmed by tree-ring dates of winter AD 1732/3 and spring AD 1733 from the east chamber above, supported by contemporary building accounts.

Finally, the latest sequence of dates related to the reconstruction of the four turrets. Eighteen samples produced 13 precise felling dates which showed a progression of repair. This started with the south-west turret, with latest felling dates of winter AD 1779/80, followed by the north-west and south-east turrets, and finally the Flamsteed Tower with latest felling dates of spring AD 1783. Again, much of this work is supported by contemporary documentary accounts.

In conclusion, the programme of dendrochronology within the White Tower has succeeded in dating all but 22 of the 155 timbers sampled. Of these dated timbers, 43 produced precise felling dates, for 7 of the 10 phases of construction studied. This corpus of dated material has been combined to produce 9 reference chronologies, many of them well replicated, covering a period of almost a millennium. These chronologies gave excellent matches with local and regional reference chronologies, suggesting that the timber was all obtained locally to London. The two medieval doors were found to be constructed of boards imported from the Baltic region, however. Through this programme of analysis, much more of the chronological development of the White Tower has been elucidated, greatly helping in the interpretation of this world-class monument for future generations.

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Table 1: Summary of tree–ring dating

Norman – Primary Phase

Sample number & type		Timber and position	Dates AD spanning	H/S bdry	Sapwood complement	No of rings	Mean width mm	Std devn mm	Mean sens mm	Felling seasons and dates/date ranges (AD)
Well in West Basement										
* **wt01**	s	Plank 1 from East (beech)	927–1081			155	1.00	0.47	0.366	
* **wt02**	s	Plank 2 from East – *ex situ* (beech)	913–1081			169	1.22	0.68	0.363	
* **wt03**	s	*Ex situ* plank (beech)	950–1070			121	1.13	0.44	0.351	
* **wt04**	s	*Ex situ* plank (beech)	909–99			91	1.81	1.34	0.257	
* **wt05**	s	*Ex situ* plank (beech)	906–1072			167	1.59	1.29	0.330	
*** = WHITOWR1**		**Site master (English Beech)**	**906–1081**			**176**	**1.51**	**1.20**	**0.310**	**After 1082**
Basement Spine Wall Drawbar Socket Lining										
wt06a	s	East side board	977–1059			83	1.25	0.33	0.231	
b	s	ditto	1003–1059			57	1.79	0.39	0.210	
c	s	ditto	984–1049			66	1.55	0.37	0.215	
wt06		Mean of **wt06a** + **wt06b** + **wt06c**	977–1059			83	1.25	0.33	0.231	After 1068
wt07	s	Bottom board	886–989			104	1.50	0.47	0.230	After 998

Key: *, †, §, ‡ = sample included in site–masters; c = core; s = section; ¼C, ½C, C = bark edge present, partial or complete ring: ¼C = spring (ring not measured), ½C = summer/autumn, or C = winter felling (ring measured); H/S bdry = heartwood/sapwood boundary – last heartwood ring date; std devn = standard deviation; mean sens = mean sensitivity. Sapwood estimate (95% confidence) of 9–41 used for English timbers (Miles 1997)

Sample number & type		Timber and position	Dates AD spanning	H/S bdry	Sapwood complement	No of rings	Mean width mm	Std devn mm	Mean sens mm	Felling seasons and dates/date ranges (AD)
Ground Floor *South Entrance Drawbar Socket Lining Fragments*										
wt08a	s	Fragment 1	958–1018			61	1.21	0.49	0.299	
b	s	ditto	958–1019			62	1.21	0.49	0.290	
c	s	ditto	940–1010			71	1.36	0.48	0.279	
wt08d	s	ditto	934–1012			79	1.39	0.52	0.281	
wt08		Mean of **wt08a** + **wt08b** + **wt08c** + **wt08d**	934–1019			86	1.32	0.52	0.262	(1049–81)
wt09a	s	Fragment 2	939–95			57	1.31	0.47	0.323	
b	s	ditto	939–88			50	1.38	0.49	0.317	
wt09		Mean of **wt09a** + **wt09b**	939–95			57	1.31	0.48	0.306	(1049–81)
* **wt10**	s	Fragment 3	940–99			60	1.02	0.36	0.236	After 1008
wt11a	s	Fragment 4	926–85			60	1.21	0.41	0.318	
b	s	ditto	926–80			55	1.23	0.44	0.328	
c	s	ditto	925–69			45	1.18	0.39	0.286	
wt11		Mean of **wt11a** + **wt11b** + **wt11c**	925–85			61	1.22	0.39	0.288	(1049–81)
wt12a	s	Fragment 5	907–92			86	1.23	0.54	0.291	
b	s	ditto	907–89			83	1.28	0.53	0.297	
wt12		Mean of **wt12a** + **wt12b**	907–92			86	1.25	0.53	0.273	(1049–81)
wt13a	s	Fragment 6	–			20	1.94	0.60	0.272	
b	s	ditto	–			21	1.83	0.42	0.228	
c	s	ditto	–			26	1.56	0.58	0.347	
wt14a	s	Fragment 7	982–1041			60	0.94	0.32	0.272	
b	s	ditto	982–1041			60	0.95	0.32	0.253	
wt14		Mean of **wt14a** + **wt14b**	982–1041			60	0.95	0.32	0.246	(1049–81)
Ground Floor *Spine Wall Drawbar Socket Lining*										
wt15	mc	Bottom board	945–1028			84	1.35	0.41	0.232	(1049–81)
wt16	mc	Top board	917–1012			96	1.57	0.44	0.256	(1049–81)
wt17	mc	Left–hand board	932–1039	(1040)	+1 NM to H/S	108	1.38	0.80	0.236	1049–81
wt18	mc	Right–hand board	927–1043			117	1.41	0.52	0.243	(1049–81)
* **wt0818**		Same–tree mean of **wt08** + **09** + **11** + **12** + **14–18**	907–1043			137	1.32	0.52	0.238	1049–81

Sample number & type		Timber and position	Dates AD spanning	H/S bdry	Sapwood complement	No of rings	Mean width mm	Std devn mm	Mean sens mm	Felling seasons and dates/date ranges (AD)
First Floor Embrasure Lintels										
wt19a	mc	NW embrasure, S lintel, front board	961–1023			63	1.45	0.43	0.234	
b	mc	ditto	985–1045	1046	H/S	61	1.17	0.34	0.177	
c	mc	ditto	1007–1046	1046	H/S	40	1.32	0.43	0.179	
d1	mc	ditto	–			28	1.28	0.45	0.241	
d2	mc	ditto	–			31	1.29	0.27	0.208	
e	mc	ditto	–			39	1.43	0.39	0.217	
wt19		Mean of **wt19a** + **wt19b** + **wt19c**	961–1046	1046	H/S	86	1.36	0.45	0.206	1055–87
wt20a	mc	NW embrasure, N lintel	–			21	2.07	0.58	0.331	
b	mc	ditto	–			15	1.75	0.40	0.236	
c	mc	ditto	988–1026			39	1.63	0.39	0.212	(1055–87)
* **wt21**	p	NE embrasure, S lintel, front board	968–1040	(1063)	+22 NM to H/S	73	1.65	0.43	0.227	1072–1104
* **wt1920**		Same–tree of **wt19** + **wt20c**	961–1046			86	1.43	0.46	0.209	1055–87
Second Floor Gutter Linings										
* **wt22a**	s	Drain 1, E passage, 2nd floor	816–918			103	0.86	0.22	0.189	
b	s	ditto	955–1081			127	0.81	0.18	0.144	
c	s	ditto	–			49	0.75	0.19	0.181	
d	s	ditto	970–1092			123	0.76	0.18	0.152	
* **wt22**		Mean of **wt22b** + **wt22d**	955–1092			138	0.78	0.17	0.141	After 1101
wt23a	s	Drain 8, W passage, 2nd floor (134)	926–91			66	1.18	0.37	0.223	
b	s	ditto	932–89			58	1.14	0.40	0.248	
c	s	ditto	957–1005			49	1.34	0.32	0.197	
d	s	ditto	945–79			35	1.24	0.47	0.242	
e	s	ditto	–			44	1.32	0.41	0.236	
f	s	ditto	946–70			25	1.22	0.44	0.274	
g	s	ditto	935–69			35	1.15	0.45	0.305	
h	s	ditto	974–1003			30	1.38	0.32	0.210	
i	s	ditto	958–1004			47	1.32	0.29	0.202	
j	s	ditto	–			26	1.34	0.36	0.214	
k	s	ditto	–			27	1.56	0.45	0.206	
* **wt23**		Mean of **wt23a–23d** + **23f–23i**	926–1005			80	1.25	0.38	0.229	After 1014
*** = WHTOWR2 Site Master (English)**			**816–1092**			**277**	**1.04**	**0.37**	**0.181**	

Edward III alterations

Sample number & type	Timber and position	Dates AD spanning	H/S bdry	Sapwood complement	No of rings	Mean width mm	Std devn mm	Mean sens mm	Felling seasons and dates/date ranges (AD)
Door to Basement Apsidal Room									
wt24a mc	Board 1 from West, North face	1175–1273			99	1.43	0.55	0.240	}
b		1174–1274			101	1.36	0.54	0.218	
* **wt24**	Mean of **wt24a** + **wt24b**	1174–1274			101	1.39	0.54	0.221	}
wt25a c	Board 2 from West, North face	1109–1312			204	0.80	0.20	0.223	}
b c	ditto	1120–1316			197	0.79	0.19	0.219	}
wt25	Mean of **wt25a** + **wt25b**	1109–1316			208	0.80	0.19	0.215	}
wt26a	Board 3 from West, North face	1216–81			66	0.87	0.21	0.170	
b		1161–1301			141	1.15	0.32	0.201	
* **wt26**		1161–1301			141	1.10	0.31	0.190	
* **wt27a1** c	Board 4 from West, North face	1166–1186			21	1.51	0.61	0.247	}
* **a2** c	ditto	1192–1315			124	1.06	0.32	0.217	}
* **wt28** c	Board 5 from West, North face	1160–1322			163	0.81	0.21	0.170	} After 1345
wt29 c	Board 6 from West, North face	1169–1329			161	1.04	0.23	0.185	}
wt30a1	Board 7 from West, North face	–			22	1.70	0.30	0.151	
a2	ditto	–			74	1.30	0.28	0.170	
wt31 c	Board 1 from West, South face	1137–1320			184	0.87	0.28	0.255	}
* **wt32a1**	Board 2 from West, South face	1111–1156			46	0.94	0.18	0.204	
* **a2**	ditto	1169–1321			153	0.87	0.18	0.162	
* **wt33** c	Board 3 from West, South face	1177–1337			161	0.98	0.24	0.173	}
* **wt34** c	Board 4 from West, South face	1198–1319			122	1.27	0.29	0.141	}
* **wt35**	Board 5 from West, South face	1140–1234			95	0.96	0.21	0.177	
* **wt36** c	Board 6 from West, South face	1181–1316			136	1.23	0.27	0.178	}
wt37a	Board 7 from West, South face	1162–1313			152	1.00	0.21	0.185	
b1	ditto	1155–1208			54	1.11	0.22	0.193	
b2	ditto	1234–1313			80	0.91	0.15	0.182	
wt37	Mean of **wt37a** + **wt37b1** + **wt37b2**	1155–1313			159	1.01	0.21	0.178	
wt38a c	Board 8 from West, South face	1154–1321			168	1.05	0.25	0.180	}
b c	ditto	1159–1323			165	1.06	0.25	0.161	}
* **wt38**	Mean of **wt38a** + **wt38b**	1154–1323			170	1.06	0.24	0.162	}
* **wt2537**	Mean of **wt25** + **wt29** + **wt31** + **wt37**	1109–1329			221	0.91	0.21	0.198	
* = **WHTOWR3 Site Master (Baltic)**		1109–1337			229	1.01	0.19	0.144	

Edward IV Alterations

Sample number & type		Timber and position	Dates AD spanning	H/S bdry	Sapwood complement	No of rings	Mean width mm	Std devn mm	Mean sens mm	Felling seasons and dates/date ranges (AD)
Door to Bottom of Great Vice, Flamsteed Turret										
wt39a	mc	Board 1	1280–1440			161	1.26	0.27	0.149	
b	mc	ditto	1280–1440			161	1.27	0.27	0.149	
* **wt39**		Mean of **wt39a** + **wt39b**	1280–1440			161	1.27	0.27	0.144	After 1448
wt40	mc	Board 2	1325–1449			125	1.63	0.50	0.187	After 1457
* **wt41**	mc	Board 3	1284–1432			149	1.34	0.35	0.164	After 1440
* **wt42**	mc	Board 4	1245–1411			167	1.11	0.46	0.234	After 1419
wt43	mc	Board 5	–			86	2.06	0.71	0.162	
* **wt44**	mc	Board 6	1288–1411			124	1.51	0.37	0.237	After 1419
*** = WHTOWR4 Site Master (Baltic)**			**1245–1440**			**196**	**1.31**	**0.37**	**0.167**	**Circa 1475**

Key: *, †, = sample included in site–masters; c = core; s = section; mc = micro–core; p = photo; ¼C, ½C, C = bark edge present, partial or complete ring: ¼C = spring (ring not measured), ½C = summer/autumn, or C = winter felling (ring measured); H/S bdry = heartwood/sapwood boundary – last heartwood ring date; std devn = standard deviation; mean sens = mean sensitivity. Sapwood estimate (95% confidence) of 9–41 used for English timbers (Miles 1997), 8–24 for Baltic oak boards (Tyers 1998)

Henry VII alterations – Main Roof Reconstruction

Sample number & type		Timber and position	Dates AD spanning	H/S bdry	Sapwood complement	No of rings	Mean width mm	Std devn mm	Mean sens mm	Felling seasons and dates/date ranges (AD)
West Chamber Roof										
* **wt45**	c	Tiebeam T2	1297–1462	1461	1	166	1.84	0.98	0.196	1470–1502
* **wt46**	c	Tiebeam T3	1306–1460	1459	1	155	1.67	0.77	0.198	1468–1500
* **wt47**	c	Tiebeam T4	1325–1436			112	1.63	0.52	0.232	After 1445
* **wt48**	c	Firring piece to tiebeam T4	1329–1471	1471	H/S	143	1.36	0.51	0.231	1480–1512
wt49	c	East upper purlin bay 4	1291–1468	1456	12	178	1.49	0.64	0.203	(1480–1503)
* **wt50**	c	Tiebeam T5	1324–1403			80	1.97	0.45	0.220	After 1412
* **wt51**	c	1st rafter south of T5, bay 5, east side	1342–1488	1443	45½C	147	1.04	0.40	0.223	Summer 1489
* **wt52**	c	Tiebeam T6	1286–1460	1454	6	175	1.40	0.60	0.205	1463–95
* **wt53**	c	Tiebeam T7	1357–1489	1467	22¼C	133	1.34	0.71	0.177	Spring 1490
wt54	c	West lower wall–plate bay 7	–		3	63	2.57	1.19	0.219	
wt55	c	West lower purlin bay 7	1302–1479	1468	11	178	1.91	0.67	0.207	(1480–1503)
wt56a	c	Ridge beam bay 7	1338–1470	1469	1	133	1.72	0.58	0.205	
b	c	ditto	–		15	15	1.04	0.29	0.242	
c	c	ditto	1412–89	1469	20¼C	78	1.24	0.34	0.224	
d	c	ditto	–		8¼C	8	1.21	0.31	0.198	
* **wt56**		Mean of **wt56a** + **wt56c**	1338–1489	1469	20¼C	152	1.64	0.59	0.208	Spring 1490
wt57a	c	Tiebeam T8	1310–1469	1464	5	160	1.77	0.62	0.220	
b	c	ditto	1463–1489	1463	26¼C	27	1.25	0.17	0.160	
* **wt57**		Mean of **wt57a** + **wt57b**	1310–1489	1464	25¼C	180	1.71	0.61	0.213	Spring 1490
* **wt58**	c	Tiebeam T9	1370–1470	1464	4	101	1.48	0.35	0.165	1473–1505
wt59a	c	Firring piece to tiebeam T9	1386–1465			80	1.38	0.36	0.197	
b1	c	ditto	1374–1436			63	1.41	0.47	0.214	
b2	c	ditto	1439–86	1467	19	48	1.38	0.23	0.140	
* **wt59**		Mean of **wt59a** + **wt59b1** + **wt59b2**	1374–1486	1467	19	113	1.42	0.38	0.179	1487–1508
* **wt60**	c	Tiebeam T10	1305–1470	1470	H/S	166	1.83	0.64	0.206	1479–1511
wt61a	c	East upper purlin bay 10	1399–1442			44	2.40	0.86	0.212	
b1	c	ditto	1397–1440			44	2.47	0.99	0.196	
b2	c	ditto	–			14	1.42	0.30	0.129	
* **wt61**		Mean of **wt61a** + **wt61b1**	1397–1442			46	2.45	0.92	0.194	After 1461
* **wt62**	c	Ridge beam bay 10	1383–1476	1464	12	94	2.08	0.81	0.207	1477–1505
* **wt63**	c	Tiebeam T11	1321–1470	1470	H/S	150	1.65	0.55	0.206	1479–1511

Sample number & type		Timber and position	Dates AD spanning	H/S bdry	Sapwood complement	No of rings	Mean width mm	Std devn mm	Mean sens mm	Felling seasons and dates/date ranges (AD)
East Chamber Roof										
* **wt64**	c	3rd joist from north, west end of bay 1	1367–1467	1467	H/S	101	1.68	0.73	0.198	1476–1508
wt65	c	E lower purlin bay 2	1304–1457	1457	H/S	154	1.72	0.69	0.221	(1485–1501)
wt66	c	E uppr purlin 3rd bay from N, E Chamber	1306–1484	1462	22	179	1.59	0.58	0.223	(1485–1501)
* **wt67**	c	1st rafter from N, 3rd bay from N, E Chamber	1380–1468	1468	H/S	89	1.48	0.30	0.169	1477–1509
* **wt68**	c	W lower purlin bay 3	1356–1467	1463	4	112	1.81	0.70	0.183	1472–1504
* **wt69**	c	Tiebeam T3	1350–1470	1470	H/S	121	1.84	0.51	0.227	1479–1511
wt70	c	Ridge beam bay 4	1320–1478	1472	6	159	1.55	0.56	0.227	(1486–1507)
wt71a1	c	Tiebeam T4	–			13	2.07	0.48	0.226	
a2	c	ditto	1326–1454	1449	5	129	1.27	0.40	0.212	
a3	c	ditto	1453–69	1452	17	17	0.86	0.17	0.205	
* **wt71**		Mean of **wt71a2** + **wt71a3**	1326–1469	1451	18	144	1.22	0.40	0.212	1470–92
* **wt72**	c	Tiebeam T5	1260–1469	1467	2	210	1.44	0.77	0.216	1476–1508
Chapel Roof										
wt73a	c	Tiebeam T I (East Chamber T6)	1275–1483	1473	10	209	1.53	0.47	0.191	
b	c	ditto	1473–89		17¼C	17	1.45	0.40	0.224	
c	c	ditto	1473–89	1474	15¼C	17	1.49	0.47	0.229	
* **wt73**		Mean of **wt73a** + **wt73b** + **wt73c**	1275–1489	1474	15¼C	215	1.54	0.47	0.191	Spring 1490
wt74a	c	Tiebeam T II	1301–1467			167	1.35	0.41	0.201	
b	c	ditto	1403–79	1466	13	77	1.13	0.25	0.193	
c	c	ditto	1470–88		19¼C	19	1.24	0.19	0.185	
* **wt74**		Mean of **wt74a** + **wt74b** + **wt74c**	1301–1488	1466	22¼C	188	1.32	0.41	0.202	Spring 1489
wt75	c	Ridge beam bay 2	1303–1485	1469	16	183	1.24	0.66	0.207	(1486–1507)
wt76a	c	Tiebeam T III	1361–1476	1473	3	116	1.28	0.38	0.195	
b	c	ditto	1352–1488	1473	15+(1–2C NM)	137	1.41	0.43	0.193	
c	c	ditto	–		+9¼C	9	1.65	0.23	0.181	
* **wt76**		Mean of **wt76a** + **wt76b**	1352–1488	1473	15	137	1.37	0.41	0.186	1489–90
* **wt77**	c	Ridge beam bay 3	1349–1472	1469	3	124	1.61	0.57	0.212	1478–1510
wt78a1	c	Tiebeam T IIII	1297–1368			72	2.06	0.95	0.214	
a2	c	ditto	1370–1458			89	1.07	0.36	0.217	
b1	c	ditto	1323–1392			70	1.51	0.41	0.228	
b2	c	ditto	1407–1483	1469	14	77	0.93	0.26	0.208	
* **wt78**		Mean of **wt78a1** + **b2** + **wt78b1** + **b2**	1297–1483	1469	14	187	1.47	0.81	0.207	1484–1510
* **wt79**	c	West upper wall–plate bay 4	1370–1489	1457	32C	120	1.72	0.67	0.167	Winter 1489/90
wt80	c	West lower wall–plate bay 4	–		2	95	2.53	1.44	0.177	

Sample number & type		Timber and position	Dates AD spanning	H/S bdry	Sapwood complement	No of rings	Mean width mm	Std devn mm	Mean sens mm	Felling seasons and dates/date ranges (AD)
Chapel Roof (continued)										
wt81	c	Post east end of T IIII over apse end	1270–1461	1461	H/S	192	2.03	0.83	0.201	(1486–1507)
wt82	c	Wall–plate / beam over apse end	–		H/S	96	1.99	0.69	0.189	
* **wt83**	c	10th joist from north end of apse end	1358–1489	1467	22¼C	132	1.40	0.43	0.208	Spring 1490
* **wt84**	c	West centre beam over apse end	1293–1472	1466	6	180	1.51	1.10	0.204	1476–1507
Floor Boards, Second Floor										
wt85a	s	Floorboard over spine wall 2nd floor IV–47	1336–1405			70	1.18	0.45	0.252	
b	s	ditto	1340–1406			67	1.06	0.33	0.210	
c	s	ditto	1353–1419			67	1.18	0.68	0.217	
d	s	ditto	1361–1472	1462	10	112	0.99	0.34	0.167	
wt85		Mean of **wt85a** + **wt85b** + **wt85c** + **wt85d**	1336–1472	1462	10	137	1.03	0.35	0.190	(1486–1507)
wt86	c	Floorboard over spine wall 2nd floor IV–47	1322–1425			104	1.22	0.42	0.203	(1486–1507)
* **wt87**	c	Floorboard over spine wall 2nd floor IV–55	1347–1464	1464	H/S	118	0.90	0.23	0.209	(1473–1505)
wt88a	c	Floorboard over spine wall 2nd floor V–64	1415–85	1469	16	71	1.37	0.39	0.159	
b	c	ditto	1430–87	1470	17¼C	58	1.29	0.36	0.162	
* **wt88**		Mean of **wt88a** + **wt88b**	1415–87	1470	17¼C	73	1.37	0.37	0.161	Spring 1488
* **wt4955**		Mean of **wt49** + **wt55**	1291–1479	1462	*Avg H/S bdy*	189	1.74	0.62	0.188	1480–1503
* **wt656**		Mean of **wt65** + **wt66**	1304–1484	1460	*Avg H/S bdy*	181	1.67	0.61	0.209	1485–1501
* **wt7086**		Mean of **wt70** + **wt75** + **wt81** + **wt85** + **wt86**	1303–1485	1461	*Avg H/S bdy*	183	1.35	0.63	0.196	1486–1509
First Floor East Chamber posts (Re–set)										
* **wt89**	c	1st post from N, East arcade	1357–1448			92	2.74	1.01	0.225	After 1457
* **wt90**	c	2nd post from N, West arcade	1328–1407			80	2.68	0.67	0.200	After 1416
*** = WHTOWR5 Site Master**			**1260–1489**			**230**	**1.78**	**0.60**	**0.153**	

Henry VIII Turret Repairs

Sample number & type		Timber and position	Dates AD spanning	H/S bdry	Sapwood complement	No of rings	Mean width mm	Std devn mm	Mean sens mm	Felling seasons and dates/date ranges (AD)
Flamsteed Tower – Roof										
* **wt91**	c	Lower rib	1370–1505	1505	h/s	136	1.05	0.53	0.195	1514–46
wt92a	c	Ogee brace	1457–1530	1515	16	74	1.65	0.37	0.190	
b	c	ditto	1519–31		13C	13	1.42	0.30	0.246	
* **wt92**		Mean of **wt92a** + **wt92b**	1457–1531	1515	17C	75	1.65	0.36	0.194	Winter 1531/2
* **wt93**	c	Ogee brace	1421–1504	1503	1	84	1.50	0.92	0.194	1512–44
* **wt94**	c	Upper rib	1415–1532	1509	23¼C	118	1.35	0.40	0.160	Spring 1533
* **wt95**	c	Upper rib	1423–1531	1510	21¼C	109	1.06	0.23	0.180	Spring 1532
* **wt96**	c	Ogee brace	1461–1528	1502	26	68	1.85	0.64	0.199	1529–43
South–East Turret Upper Floor Replacement										
wt97a	c	2nd joist from N, top floor frame	1409–95	1495	h/s	87	1.34	0.95	0.213	
b	c	ditto	1424–93	1493	h/s	70	1.09	0.48	0.166	
* **wt97**		Mean of **wt97a** + **wt97b**	1409–95	1494	1	87	1.38	0.95	0.197	1503–35
* **wt98**	c	3rd joist from N, top floor frame	1407–1508			102	2.05	1.80	0.196	After 1515
wt99a1	c	4th joist from N, top floor frame	–			25	2.83	0.71	0.198	
b1	c	ditto	–			25	3.11	0.66	0.202	
wt99ab1		Mean of **wt39a1** + **wt39b1**	–			26	2.98	0.65	0.203	
wt99a2	c	4th joist from N, top floor frame	–			40	2.98	1.07	0.275	
b2	c	ditto	–			44	2.86	1.09	0.298	
wt99ab2		Mean of **wt39a2** + **wt39b2**	–			44	2.91	1.06	0.289	
South–West Turret – Top Floor Joists										
wt100	c	Top floor joist 1st from N	1–60†		h/s	60	1.59	0.54	0.173	
wt101a	c	Top floor joist 2nd from N	–		*2*	*37*	*1.91*	*0.67*	*0.234*	
b	c	ditto	–		*1*	*33*	*2.75*	*0.87*	*0.242*	
c	c	ditto	–		*3*	*45*	*1.51*	*0.64*	*0.248*	
wt101		Mean of **wt102a** + **wt102b** + **wt102c**	21–65†			45	2.04	0.61	0.195	
wt102	c	Top floor joist 3rd from N	9–56†		h/s	48	1.88	0.54	0.159	
wt103	c	Top floor joist 4th from N	10–65†		h/s	56	1.76	0.81	0.221	
wt104	c	Top floor joist 5th from N	3–61†		h/s	59	2.32	0.60	0.182	
wt1004		Mean of **wt100–wt104**	1–65†			65	1.93	0.54	0.139	
			(† = years of composite wt1004)							
South–East Turret – Main Roof Level Floor Frame										
* **wt105**	c	East floor beam, main roof level	1411–1513	1513	H/S	103	1.74	0.69	0.229	1522–54
* **wt106**	c	South joist, main roof level	1449–1531	1506	25¼C	83	1.61	0.64	0.260	Spring 1532
*** = WHTOWR6 Site Master**			**1370–1532**			**163**	**1.62**	**0.68**	**0.156**	

Elizabeth I Alterations

Sample number & type		Timber and position	Dates AD spanning	H/S bdry	Sapwood complement	No of rings	Mean width mm	Std devn mm	Mean sens mm	Felling seasons and dates/date ranges (AD)
First Floor East Chamber posts										
* **wt107**	c	6th post from N, West arcade	1483–1565	1545	20C	83	2.28	1.14	0.295	Winter 1565/6

James I Alterations

Sample number & type		Timber and position	Dates AD spanning	H/S bdry	Sapwood complement	No of rings	Mean width mm	Std devn mm	Mean sens mm	Felling seasons and dates/date ranges (AD)
Ground Floor West Chamber Posts and Beams										
* **wt108**	c	1st post from N, East arcade	1497–1578			82	1.75	0.56	0.229	After 1587
* **wt109**	c	2nd post from N, East arcade	1526–1601	1582	19½C	82	2.45	1.04	0.203	Summer 1602
* **wt110**	c	E arcade beam 3rd bay from N,	1491–1591	1583	8	101	2.24	0.65	0.227	1592–1624
wt111a	c	Floor beam W Chamber GF between 6/7p	1495–1591	1591	H/S	97	1.80	0.59	0.239	
b	c	ditto	1493–1549			57	0.90	0.24	0.212	
c	c	ditto	1493–1587	1585	2	95	1.38	0.48	0.200	
* **wt111**		Mean of **wt111a** + **wt111b** + **wt111c**	*1493–1591*	*1588*	*3*	*99*	*1.45*	*0.36*	*0.203*	*1597–1629*
* **wt112**	c	3rd post W arcade W Chamber GF	1521–1600	1588	12	80	2.18	0.77	0.229	1601–29
* **wt113**	c	5th post W arcade W Chamber GF	1504–1602	1583	19C	99	2.18	0.77	0.231	Winter 1602/3
wt114	c	1st joist between posts 3 & 4 W arcade	–		10¼C	47	2.59	1.00	0.221	
wt115	c	4th joist between posts 3 & 4 W arcade	–		14C	31	2.87	0.84	0.175	
* **wt116**	c	9th post W arcade W Chamber GF	1474–1602	1583	19 ?C	129	1.53	1.19	0.208	?Winter 1602/3
First Floor West Chamber Posts and Ceiling										
* **wt117**	c	2nd post from N, West arcade	1516–1602	1584	18C	87	1.69	0.54	0.187	Winter 1602/3
* **wt118**	c	4th post from N, East arcade	1463–1601	1587	14½C	139	2.00	0.50	0.155	Summer/autumn 1602
* **wt119**	c	5th post from N, West arcade	1518–1602	1577	25C	85	1.73	0.63	0.196	Winter 1602/3
wt120	c	6th post from N, West arcade	–		21C	85	1.58	1.22	0.220	
* **wt121**	c	2nd joist from N, West side	1556–1602	1591	11¼C	47	4.42	1.42	0.185	Spring 1603
* **wt122**	c	3rd joist from N, West side	1520–1602	1591	11C	83	2.11	0.75	0.191	Winter 1602/3
wt123	c	6th joist from N, West side	–		20¼C	164	0.98	0.85	0.221	
wt124a	c	10th joist from N, West side	1480–1594	1578	16	115	1.40	0.30	0.168	
b	c	ditto	1567–1602	1580	22C	36	1.85	0.33	0.139	
* **wt124**		Mean of **wt124a** + **wt124b**	1480–1602	*1579*	*23C*	123	1.47	0.33	0.162	Winter 1602/3
* **wt125**	c	28th joist from N, West side	1472–1602	1580	22¼C	131	1.85	0.82	0.183	Spring 1603
wt126a	c	33rd joist from N, centre	–			58	1.76	0.73	0.227	
b	c	ditto	–		44C	82	0.75	0.42	0.213	
* **wt127**	c	Main beam, West arcade to S of 6th post	1489–1602	1581	21C	114	1.56	0.38	0.184	Winter 1602/3

Sample number & type		Timber and position	Dates AD spanning	H/S bdry	Sapwood complement	No of rings	Mean width mm	Std devn mm	Mean sens mm	Felling seasons and dates/date ranges (AD)
South–West Turret – Diagonal Ties										
* **wt128**	c	SE–NW diag. beam at head of stairs	1522–1616	1600	16C	95	1.95	0.64	0.232	Winter 1616/7
wt129a	c	NE–SW diag. beam above top floor	1520–1611	1597	14	92	2.16	0.75	0.197	
b	c	ditto	1593–1616	1598	18	14	1.53	0.31	0.186	
* **wt129**		Mean of **wt129a** + **wt129b**	1520–1616	1598	18	97	2.10	0.77	0.189	1617–39
* **wt130**	c	SE diag. beam above top floor	1517–1599	1598	1	83	1.64	0.44	0.207	1607–39
*** = WHTOWR7 Site Master**			**1463–1616**			**154**	**2.04**	**0.52**	**0.140**	

George II Alterations

Sample number & type		Timber and position	Dates AD spanning	H/S bdry	Sapwood complement	No of rings	Mean width mm	Std devn mm	Mean sens mm	Felling seasons and dates/date ranges (AD)
Insertion of Basement Vaults and Reconstruction of Chambers above										
* **wt131**	c	Floor beam East Chamber GF	1668–1710	1710	H/S	43	2.30	0.65	0.230	1719–51
* **wt132**	c	2nd post from N E arcade E Chamber GF	1645–1732	1708	24 ?C	88	2.34	1.16	0.266	?Winter 1732/3
wt133a	c	Joist E arcade 5th post 3rd joist E Chamber GF	–		14	59	2.09	1.13	0.227	
b	c	ditto	–		20¼C	54	2.00	1.17	0.318	
wt133		Mean of **wt133a** + **wt133b**	–		20 ¼C	65	2.11	1.11	0.257	
* **wt134**	c	Floor beam East Chamber GF	1667–1732	1713	19C	66	2.22	0.74	0.192	Winter 1732/3
wt135a	c	Floor beam East Chamber GF	1656–90			35	3.14	0.78	0.188	
b	c	ditto	1656–1714	1714	H/S	59	2.27	0.88	0.231	
* **wt135**		Mean of **wt135a** + **wt135b**	1656–1714	1714	H/S	59	2.27	0.88	0.231	1723–55
wt136a	c	4th post W arcade West Chamber GF	1668–1732	1718	14¼C	65	2.17	0.98	0.234	
b	c	ditto	1694–1732	1718	14	39	1.56	0.42	0.250	
* **wt136**		Mean of **wt136a** + **wt136b**	1668–1732	1718	14¼C	65	2.17	0.97	0.222	Spring 1733
* **wt137**	c	6th post E arcade West Chamber GF	1674–1732	1721	11C	59	2.80	0.87	0.188	Winter 1732/3
*** = WHTOWR8 Site Master**			**1645–1732**			**88**	**2.30**	**0.73**	**0.166**	

George III Repairs

Sample number & type		Timber and position	Dates AD spanning	H/S bdry	Sapwood complement	No of rings	Mean width mm	Std devn mm	Mean sens mm	Felling seasons and dates/date ranges (AD)
South–East Turret										
* **wt138**	c	E–W centre beam to roof	1703–80	1761	19C	78	3.35	1.67	0.248	Winter 1780/81
wt139a	c	West perimeter beam to roof	1696–1773	1756	17	78	2.04	0.76	0.193	
b	c	ditto	1700–21			22	2.37	0.72	0.181	
c	c	ditto	1735–80	1758	22¼C	46	1.28	0.64	0.239	
* **wt139**		Mean of **wt139a** + **wt139b** + **wt139c**	1696–1780	1758	22¼C	85	1.89	0.81	0.199	Spring 1781
wt140	c	North perimeter beam to roof	–		9C	27	2.41	0.59	0.214	
South–West Turret										
* **wt141**	c	S brace to centre post	1679–1778	1758	20C	100	1.32	0.83	0.216	Winter 1778/9
* **wt142**	c	N brace to centre post	1680–1779	1760	19C	100	1.56	0.46	0.232	Winter 1779/80
North–West Turret										
wt143a1	c	Top floor joist SE corner	–		1	29	1.99	0.78	0.272	
a2	c	ditto	–		31½C	31	1.13	0.43	0.180	
b1	c	ditto	–		2	15	3.19	0.63	0.128	
b2	c	ditto	–		37½C	37	1.13	0.57	0.148	
wt144a1	c	Top floor SE diagional beam	–			48	0.97	0.61	0.212	
a2	c	ditto	–		19C	67	1.75	1.19	0.240	
wt145a	c	Axial beam, top floor frame	1722–78	1767	11	57	2.60	0.82	0.237	
b	c	ditto	1767–80	1766	14C	14	2.38	0.92	0.194	
* **wt145**		Mean of **wt145a** + **wt145b**	1722–80	1766	14C	59	2.54	0.81	0.226	Winter 1780/81
* **wt146**	c	NW diagonal beam, top floor frame	1629–1776	1723	53¼C	148	1.20	0.76	0.223	Spring 1777
* **wt147**	c	East perimeter beam to roof	1688–1770	1756	14	83	1.42	0.58	0.241	1771–97
wt148a	c	S brace to king post to roof	1700–79	1762	17C	80	2.09	0.68	0.181	
b	c	ditto	1750–79	1763	16C	30	1.88	0.41	0.207	
* **wt148**		Mean of **wt148a** + **wt148b**	1700–79	1763	16C	80	2.06	0.67	0.177	Winter 1779/80
wt149	c	N inner sill beam	–		29¼C	96	1.42	0.97	0.335	
* **wt150**	c	Main N–S centre beam to roof	1694–1779	1764	15C	87	2.10	0.61	0.213	Winter 1779/80
* **wt151**	c	NE beam top frame	1710–1780	1760	20C	71	1.98	0.89	0.198	Winter 1780/81
Flamsteed Tower										
* **wt152**	c	Main cross–beam to roof	1690–1782	1768	14C	93	2.12	0.76	0.260	Winter 1782/3
* **wt153**	c	NE upper principal rib	1731–82	1769	13¼C	52	3.08	0.74	0.137	Spring 1783
* **wt154**	c	SE upper principal rib	1726–82	1764	18¼C	57	2.72	1.10	0.210	Spring 1783
* **wt155**	c	SW upper principal rib	1731–82	1767	15¼C	52	2.69	0.75	0.137	Spring 1783
* = WHTOWR9 Site Master			1629–1782			154	1.99	0.58	0.178	

Table 2: Matrix of *t* -values and overlaps for components of **WHTOWR1**

Sample:	**wt02**	**wt03**	**wt04**	**wt05**
Last ring date AD:	1081	1070	999	1072
wt01	17.69 155	15.06 121	15.10 73	14.18 146
	wt02	22.31 121	13.04 87	24.19 160
		wt03	9.87 50	20.95 121
			wt04	10.06 91

Table 3: Ring-width data for site master curve **WHTOWR1**, AD 906–1081. Beech planks at bottom of well, 176 rings, starting date AD 906

ring widths (0.01mm)

751	503	595	649	640	641	518	393	324	220
380	436	442	373	305	336	347	323	265	179
287	201	181	164	164	194	130	123	135	213
219	251	211	108	136	231	167	169	125	112
156	140	101	84	76	107	108	116	96	76
35	71	145	129	89	113	112	54	78	54
96	125	130	110	65	45	55	83	117	85
75	117	82	116	95	43	65	95	94	115
130	78	89	79	105	112	60	82	107	55
103	121	109	102	119	69	147	153	110	74
95	174	108	132	61	127	180	144	172	137
125	65	145	80	156	123	112	101	89	71
90	121	97	121	103	64	85	141	129	51
137	101	37	69	130	206	173	67	42	75
50	33	126	110	108	132	78	57	82	106
125	97	98	148	99	137	135	83	73	124
140	140	129	136	115	167	197	147	98	115
161	82	155	195	133	110				

number of samples in master

1	1	1	2	2	2	2	3	3	3
3	3	3	3	3	3	3	3	3	3
3	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5
5	5	5	5	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	3	3	2	2	2
2	2	2	2	2	2				

Table 4: Dating of **WHTOWR1** against beech reference chronologies at AD 1081

Reference chronology	**Spanning**	**Overlap**	***t*-value**
Netherlands Vlaardingen *(Hanraets pers comm)*	841–1042	137	5.91
Hampshire Winchester The Brooks *(Hillam pers comm)*	906–1038	133	6.20
France Téteghem *(Girardclos & Bourquin-Mignot pers comm)*	947–1057	111	8.83
City of London BUF90 *(Tyers pers comm)*	864–1104	176	9.23
City of London DGH86 *(Tyers pers comm)*	817–1093	176	9.46
City of London IHA89 *(Tyers pers comm)*	876–1097	176	9.59
City of London TEX88 *(Tyers pers comm)*	966–1135	116	9.96
City of London CID90 *(Tyers pers comm)*	862–1091	176	10.11

Table 5: Matrix of *t* -values and overlaps for components of **wt06**

Sample:	**wt06b**	**wt06c**
Last ring date AD:	1059	1049
wt06a	11.37 57	13.26 66
	wt06b	15.38 47

Table 6: Matrix of *t* -values and overlaps for components of **wt08**

Sample:	**wt08b**	**wt08c**	**wt08d**
Last ring date AD:	1019	1010	1012
wt08a	24.40 61	17.29 53	17.48 55
	wt08b	20.13 53	20.83 55
		wt08c	17.00 71

Table 7: Combining of individual samples to form same-tree means

Samples:	*t - value:*	*overlap:*	*combined mean:*
wt09a + **wt09b**	23.66	50	**wt09**
wt12a + **wt12b**	17.82	83	**wt12**
wt14a + **wt14b**	14.39	60	**wt14**
wt19 + **wt20c**	8.59	39	**wt1920**
wt22b + **wt22d**	11.90	112	**wt22**
wt24a + **wt24b**	26.38	99	**wt24**
wt25a + **wt25b**	24.19	193	**wt25**
wt38a + **wt38a**	7.32	163	**wt423**
wt39a + **wt39b**	24.28	161	**wt39**
wt56a + **wt56c**	20.56	152	**wt56**
wt57a + **wt57b**	3.79	7	**wt57**
wt61a + **wt61b1**	10.56	42	**wt61**
wt76a + **wt76b**	14.50	116	**wt76**
wt88a + **wt88b**	10.13	56	**wt88**
wt49 + **wt55**	10.64	167	**wt4955**
wt65 + **wt66**	14.95	152	**wt656**
wt92a + **wt92b**	7.88	12	**wt92**
wt97a + **wt97b**	10.54	70	**wt97**
wt99a1 + **wt99a2**	7.15	24	**wt99ab1**
wt99a2 + **wt99b2**	24.96	40	**wt99ab2**
wt124a + **wt124b**	4.57	28	**wt124**
wt129a + **wt129b**	7.06	19	**wt129**
wt133a + **wt133a**	15.53	48	**wt133**
wt135a + **wt135b**	4.33	35	**wt135**
wt136a + **wt136b**	26.90	39	**wt136**
wt145a + **wt148b**	5.41	12	**wt145**
wt148a + **wt148b**	8.30	30	**wt148**

Table 8: Matrix of *t* -values and overlaps for components of **wt11**

Sample:	**wt11b**	**wt11c**
Last ring date AD:	980	984
wt11a	24.42 55	6.12 59
	wt11b	6.32 55

Table 9: Matrix of *t* -values and overlaps for components of **wt0818**

Sample:	**wt09**	**wt11**	**wt12**	**wt14**	**wt15**	**wt16**	**wt17**	**wt18**
Last ring date AD:	995	985	991	1041	1028	1012	1039	1043
wt08	15.54 57	5.74 52	5.65 58	12.49 38	14.24 75	11.11 79	9.34 86	9.25 86
wt09		5.25 47	5.81 53	2.99 14	8.18 51	8.59 57	7.26 57	7.32 57
wt11			14.33 61	0.73 61	8.49 41	12.34 61	5.97 54	8.45 59
wt12				1.69 10	6.50 47	10.60 75	5.70 60	6.65 65
wt14					7.05 47	6.10 31	9.89 58	8.05 60
wt15						11.67 68	8.35 84	10.69 84
wt16							10.05 81	16.27 86
wt17								10.96 108

Table 10: Matrix of *t* -values and overlaps for components of **wt19**

Sample:	**wt19b**	**wt19c**
Last ring date AD:	1045	1046
wt19a	7.50 39	4.61 17
wt19b		11.83 39

Table 11: Matrix of *t* -values and overlaps for components of **wt23**

Sample:	**wt23b**	**wt23c**	**wt23d**	**wt23f**	**wt23g**	**wt23h**	**wt23i**
Last ring date AD:	989	1005	979	970	969	1003	1004
wt23a	15.02 58	7.94 35	9.45 35	11.16 25	15.27 35	4.56 18	8.38 34
wt23b		6.05 33	11.24 35	11.12 25	14.39 35	2.75 16	5.68 32
wt23c			6.37 23	3.41 14	3.57 13	12.71 30	14.96 47
wt23d				6.26 25	10.04 25	0.00 6	8.01 22
wt23f					10.08 24	0.00 0	4.56 13
wt23g						0.00 0	4.87 12
wt23h							7.68 30

Table 12: Matrix of *t* -values and overlaps for components of **WHTOWR2**

Sample:	**wt1920**	**wt10**	**wt21**	**wt22a**	**wt22**	**wt23**
Last ring date AD:	1046	999	1040	918	1092	1005
wt0818	5.48 83	8.62 60	5.09 73	0.00 12	4.62 89	4.50 80
wt1920		1.97 39	2.86 73	0.00 0	5.43 86	2.63 45
wt10			3.75 32	0.00 0	2.31 45	2.98 60
wt21				0.00 0	3.21 73	3.26 38
wt22a					0.00 0	0.00 0
wt22						3.10 51

Table 13: Ring-width data for site master curve **WHTOWR2**, AD 816–1092. Norman phase, seven-tree mean, 277 rings, starting date AD 816

ring widths (0.01mm)

69	80	113	141	118	159	137	63	60	97
134	83	70	79	73	85	77	98	99	80
90	120	57	66	70	97	94	107	120	110
75	77	66	68	74	67	107	95	94	129
106	94	91	59	70	59	75	77	93	91
106	93	129	119	87	65	64	83	79	92
124	78	97	119	86	104	78	67	69	78
98	96	79	97	92	91	104	72	73	75
71	65	93	70	87	73	78	98	92	96
87	122	123	105	135	150	208	170	124	89
85	74	98	135	155	156	263	267	187	168
99	111	116	170	120	104	205	123	177	122
171	171	172	189	80	76	62	61	73	121
133	162	203	148	199	135	100	79	63	64
80	101	119	118	126	145	127	165	143	112
135	142	163	117	121	119	135	150	118	144
125	170	111	155	170	113	125	141	101	132
130	106	122	152	110	107	117	139	129	117
114	124	129	172	160	141	119	145	158	136
122	144	169	148	119	121	146	129	89	109
97	120	91	112	107	129	128	123	129	105
127	99	89	96	104	99	102	87	75	108
92	114	87	97	97	97	81	75	54	65
68	65	50	48	39	37	39	44	42	53
48	48	55	64	78	80	92	115	99	65
83	102	86	67	73	70	72	75	92	82
102	85	77	83	86	56	78	79	83	76
95	72	61	77	58	64	97			

number of samples in master

1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	2	2
2	2	2	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2
2	2	2	2	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	4
4	4	4	4	4	5	5	5	5	5
5	5	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6
6	6	6	6	5	5	5	5	5	5
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	3	3	3	2	2
2	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1			

Table 14: Dating of **WHTOWR2** against reference chronologies at AD 1092

Reference chronology	Spanning	Overlap	*t*-value
WMNSTR1 *(Miles and Bridge 2005)*	924–1030	107	5.93
WESTWICK *(Howard et al 1999)*	940–1179	153	6.25
REF6 *(Fletcher 1977)*	778–1199	277	6.52
GREENSTD *(Tyers 1996)*	878–1053	176	6.62
OXON93 *(Haddon-Reece et al 1993)*	632–1987	277	6.77
KEMPLEY2 *(Miles and Worthington 1999)*	960–1099	133	7.71
HANTS02 *(Miles 2003)*	443–1972	277	9.37
LONDON *(Tyers pers comm)*	413–1728	277	13.40

Chronologies in **bold** denote regional masters

Table 15: Dating of **wt06** (AD 977–1059) against reference chronologies at AD 1059

	Reference chronology	Spanning	Overlap	*t*-value
	WALES97 *(Miles 1997)*	404–1981	83	5.92
	REF75 *(Fletcher 1977)*	845–1298	83	6.10
	BRISTOL *(Hillam 1994)*	770–1320	83	6.39
	SOUTH *(Hillam and Groves 1994)*	406–1594	83	6.58
	REF6 *(Fletcher 1977)*	778–1199	83	6.74
‡	WINCHSTR *(Hillam 1992)*	443–1128	83	7.84
	LONDON *(Tyers pers comm)*	413–1728	83	8.82
	HANTS02 *(Miles 2003)*	443–1972	83	9.61

Chronologies in **bold** denote regional masters
‡ Component of HANTS02

Table 16: Dating of **wt07** (AD 886–989) against reference chronologies at AD 989

	Reference chronology	Spanning	Overlap	*t*-value
	REF6 *(Fletcher 1977)*	778–1199	104	4.42
	SOMRST04 *(Miles unpubl)*	770–1979	104	4.89
	HILLAM *(Hillam pers comm)*	404–1216	104	4.98
	GREENSTD *(Tyers 1996a)*	878–1053	104	5.02
	sc2 *(Miles and Worthington 1997)*	925–1033	65	5.00
	HANTS02 *(Miles 2003)*	443–1972	104	5.35
	LONDON *(Tyers pers comm)*	413–1728	104	6.18
	SOUTH *(Hillam and Groves 1994)*	406–1594	104	6.92
‡	WINCHSTR *(Hillam 1992)*	443–1128	104	6.96

Chronologies in **bold** denote regional masters
‡ Component of HANTS02

Table 17: Matrix of *t* -values and overlaps for components of **wt37**

Sample:	**wt37b1**	**wt37b2**
Last ring date AD:	1208	1313
wt37a	17.09	11.69
	47	80
	wt37b1	0.00
		0

Table 18: Matrix of *t* -values and overlaps for components of **wt2537**

Sample:	**wt29**	**wt31**	**wt37**
Last ring date AD:	1329	1320	1313
wt25	9.56	12.38	13.12
	148	180	159
	wt29	11.34	10.80
		152	145
		wt31	10.45
			159

Table 19: Matrix of *t*-values and overlaps for components of **WHTOWR3**

Sample:	**wt24**	**wt26**	**wt27a1**	**wt27a2**	**wt28**	**wt32a1**	**wt32a2**	**wt33**	**wt34**	**wt35**	**wt36**	**wt38**
Last ring date AD:	1274	1301	1186	1315	1322	1156	1321	1337	1319	1234	1316	1323
wt2537	8.51 101	10.68 141	3.49 21	8.56 124	11.35 163	3.66 46	5.72 153	9.98 153	8.05 122	6.80 95	11.25 136	11.93 170
	wt24	4.38 101	1.74 13	5.01 83	6.80 101	0.00 0	1.37 101	5.95 98	5.49 77	0.52 61	5.84 94	5.91 101
		wt26	1.19 21	4.53 110	6.12 141	0.00 0	4.67 133	6.54 125	9.36 104	2.31 74	7.27 121	7.24 141
			wt27a1	0.00 0	2.11 21	0.00 0	1.34 18	1.47 10	0.00 0	2.10 21	0.00 6	2.60 21
				wt27a2	4.81 124	0.00 0	3.00 124	4.68 124	7.41 118	0.78 43	7.38 124	5.21 124
					wt28	0.00 0	2.95 153	7.45 146	5.09 122	1.80 75	6.50 136	5.37 163
						wt32a1	0.00 0	0.00 0	0.00 0	3.47 17	0.00 0	0.00 0
							wt32a2	2.44 145	4.66 122	1.99 66	3.79 136	5.43 153
								wt33	5.16 122	2.57 58	6.21 136	5.73 147
									wt34	0.00 37	8.02 119	5.88 122
										wt35	0.87 54	4.68 81
											wt36	4.94 136

Table 20: Ring-width data for site master curve **WHTOWR3**, AD 1109–1337. Basement door to apsidal room, 14-board mean (Baltic oak), 229 rings, starting date AD 1109

ring widths (0.01mm)

58	82	107	101	108	101	104	61	86	60
80	80	88	107	82	87	88	81	71	89
53	94	85	70	80	107	90	75	81	77
85	82	92	83	109	82	79	79	105	131
118	109	70	63	95	91	78	83	101	120
105	147	129	119	102	112	116	114	85	124
77	123	95	81	100	98	94	116	106	94
117	111	114	138	126	96	137	153	149	140
120	124	113	87	98	112	146	135	157	152
111	122	132	89	134	134	131	97	104	131
117	138	146	136	132	123	101	89	88	96
131	110	90	84	82	77	101	81	74	90
98	122	100	118	109	101	88	94	121	100
89	78	76	76	72	77	93	79	114	102
105	111	100	101	111	110	134	99	117	77
102	82	80	90	96	117	96	127	98	103
97	87	92	97	102	94	116	83	102	97
115	110	116	113	91	90	106	96	72	73
76	74	87	80	91	105	95	114	113	110
115	103	96	124	101	88	97	93	89	96
107	100	110	107	118	109	102	111	90	88
98	100	114	124	122	101	119	98	101	109
109	87	77	106	90	93	110	121	131	2

number of samples in master

1	1	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2
2	3	3	3	3	3	3	3	3	3
3	3	3	3	3	4	4	4	3	3
3	4	5	5	5	5	5	6	6	6
7	7	7	7	7	8	8	8	9	9
9	9	10	10	10	10	10	10	9	9
9	9	9	10	10	10	10	10	10	11
11	11	11	11	11	11	11	11	11	11
11	11	11	11	11	11	11	11	11	11
11	11	11	11	11	11	11	11	11	11
11	11	11	11	11	11	10	10	10	10
10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	9	9	9	9
9	9	9	9	9	9	9	9	9	9
9	9	9	9	9	9	9	9	9	9
9	9	9	8	8	8	8	8	8	8
8	8	8	8	8	8	8	7	6	6
6	5	5	4	3	2	2	2	2	2
1	1	1	1	1	1	1	1		

Table 21: Dating of **WHTOWR3** against reference chronologies at AD 1337

Reference chronology	**Spanning**	**Overlap**	***t*-value**
BALTIC1 *(Hillam and Tyers 1995)*	1156–1597	182	4.47
BALTIC2 *(Hillam and Tyers 1995)*	1257–1615	81	4.78
GAS-T10 *(Tyers 1996b)*	1052–1370	229	5.97
WMNSTR5 *(Miles and Bridge 2005)*	1162–1330	169	6.76
STHELEN2 *(Miles and Haddon-Reece 1995)*	1216–1416	122	7.51
GRIMSBY1 *(Groves 1992)*	1100–1405	229	7.70
NWCOLLG2 *(Worthington and Miles 2006)*	1086–1357	229	8.14
MAGDALN2 *(Miles and Worthington 2000)*	1080–1416	229	8.26
REF4 *(Fletcher 1977)*	1124–1403	214	8.82

Chronologies in **bold** denote regional masters

Table 22: Matrix of *t* -values and overlaps for components of **WHTOWR5**

Sample:	**wt41**	**wt42**	**wt44**
Last ring date AD:	1432	1411	1411
wt39	6.28 149	4.51 132	4.95 124
wt41		4.29 128	4.65 124
wt42			3.90 124

Table 23: Ring-width data for site master curve **WHTOWR4**, AD 1245–1440. Door to east basement room from bottom of Great Vice, Baltic oak, 196 rings, starting date AD 1245

ring widths (0.01mm)

183	154	129	85	118	178	165	115	139	139
216	146	166	84	139	129	93	142	95	242
187	138	86	153	373	263	316	219	180	230
122	132	101	85	95	130	134	137	161	139
138	147	156	177	164	148	147	108	131	157
158	160	172	148	133	124	136	160	142	120
109	94	73	106	130	139	125	154	168	137
135	134	131	128	118	145	145	147	112	99
130	148	139	140	130	117	135	132	126	154
133	173	105	107	120	114	110	136	120	124
146	129	154	137	128	110	125	117	112	96
100	119	73	80	127	130	133	151	173	104
133	147	155	137	127	91	135	104	117	134
133	152	153	160	146	144	171	141	120	139
96	133	117	133	128	112	111	131	139	122
98	150	97	117	132	141	111	127	100	117
113	117	121	139	107	120	130	144	122	108
121	129	117	116	106	91	91	81	67	92
90	91	76	75	89	81	75	78	81	86
103	127	109	115	127	136				

number of samples in master

1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	2	2	2	2	3
3	3	3	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	2	2	2
2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	1	1
1	1	1	1	1	1				

Table 24: Dating of **WHTOWR4** against reference chronologies at AD 1440

Reference chronology	Spanning	Overlap	*t*-value
GRIMSBY1 *(Groves 1992)*	1100–1405	161	3.67
WMNSTR5 *(Miles and Bridge 2005)*	1162–1330	86	3.72
NWCOLLG2 *(Worthington and Miles 2006)*	1086–1357	113	3.93
MAGDALN2 *(Miles and Worthington 2000)*	1080–1416	172	4.91
HULLBLDS *(Hillam 1991)*	1148–1464	196	5.06
REF4 *(Fletcher 1977)*	1124–1403	159	5.44
WNCHSTR1 *(Miles and Haddon-Reece 1996)*	1207–1495	196	8.42
MAGDALN3 *(Miles and Worthington 2000)*	1222–1494	196	8.96
BALTIC1 *(Hillam and Tyers 1995)*	1156–1597	196	10.01

Chronologies in **bold** denote regional masters

Table 25: Dating of **wt40** against reference chronologies at AD 1449

Reference chronology	Spanning	Overlap	*t*-value
SARUMBP3 *(Miles and Worthington 2000)*	1088–1400	76	3.52
GRIMSBY1 *(Groves 1992)*	1100–1405	81	3.83
MAGDALN2 *(Miles and Worthington 2000)*	1080–1416	92	4.10
REF4 *(Fletcher 1977)*	1124–1403	79	4.36
BALTIC2 *(Hillam and Tyers 1995)*	1257–1615	125	4.61
REF2 (*Fletcher 1977)*	1244–1611	125	4.88
BALTIC1 *(Hillam and Tyers 1995)*	1156–1597	125	4.97

Chronologies in **bold** denote regional masters

Table 26: Matrix of *t* -values and overlaps for components of **wt59**

Sample:	**wt59b1**	**wt59b2**
Last ring date AD:	1436	1486
wt59a	11.91	4.40
	51	27
	wt59b1	0.00
		0

Table 27: Matrix of *t* -values and overlaps for components of **wt73**

Sample:	**wt73b**	**wt73c**
Last ring date AD:	1489	1489
wt73a	4.99	2.73
	11	11
	wt73b	5.13
		17

Table 28: Matrix of *t* -values and overlaps for components of **wt74**

Sample:	**wt74b**	**wt74c**
Last ring date AD:	1479	1488
wt74a	16.55	0.00
	65	0
	wt74b	5.11
		10

Table 29: Matrix of *t* -values and overlaps for components of **wt78**

Sample:	**wt78a2**	**wt78b1**	**wt78b2**
Last ring date AD:	1458	1392	1483
wt78a1	0.00 0	13.89 46	0.00 0
	wt78a2	5.35 23	9.52 52
		wt78b1	0.00 0

Table 30: Matrix of *t* -values and overlaps for components of **wt85**

Sample:	**wt85b**	**wt85c**	**wt85d**
Last ring date AD:	1406	1419	1472
wt85a	7.19 66	6.53 53	4.88 45
	wt85b	3.49 54	4.47 46
		wt85c	2.86 59

Table 31: Matrix of *t* -values and overlaps for components of **wt7086**

Sample:	**wt75**	**wt81**	**wt85**	**wt86**
Last ring date AD:	1485	1461	1472	1425
wt70	10.33 159	6.52 142	11.55 137	11.16 104
	wt75	7.09 159	8.47 137	8.62 104
		wt81	5.75 126	3.77 104
			wt85	10.57 90

Table 32: Matrix of *t* -values and overlaps for components of **WHTOWR5**

Sample:	**wt46**	**wt47**	**wt48**	**wt4955**	**wt50**	**wt51**	**wt52**	**wt53**	**wt56**	**wt57**	**wt58**	**wt59**	**wt60**	**wt61**	**wt62**	**wt63**	**wt64**	**wt656**	**wt67**	**wt7086**	**wt68**	**wt69**	**wt71**	**wt72**	**wt73**	**wt74**	**wt76**	**wt77**	**wt78**	**wt79**	**wt81**	**wt83**	**wt84**	**wt87**	**wt88**	**wt89**	**wt90**
Last ring date AD:	1460	1436	1471	1479	1403	1488	1460	1489	1489	1489	1470	1486	1470	1442	1476	1470	1467	1484	1468	1485	1467	1470	1469	1469	1489	1488	1488	1472	1483	1489	1461	1489	1472	1464	1487	1448	1407
wt45	12.13 155	8.28 112	9.04 134	13.71 166	7.84 80	6.95 121	3.15 164	4.57 106	5.38 125	9.05 153	5.88 93	4.32 89	6.33 158	5.09 46	2.51 80	5.52 142	2.25 96	12.37 159	4.40 83	5.92 160	2.04 107	0.92 113	7.56 137	8.06 166	7.81 166	6.47 162	4.41 111	5.28 114	8.21 166	2.36 93	11.42 165	4.55 105	6.89 166	3.42 116	5.21 48	4.27 92	6.91 80
wt46		10.55 112	6.67 132	10.80 155	7.28 80	7.64 119	3.84 155	4.66 104	4.91 123	7.79 151	3.74 91	5.89 87	5.88 155	3.50 46	2.06 78	5.21 140	0.90 94	8.74 155	3.37 81	7.10 155	3.00 105	0.96 111	5.18 135	6.13 155	9.05 155	5.77 155	4.45 109	6.10 112	8.30 155	2.53 91	8.58 155	3.33 103	7.41 155	2.79 114	1.22 46	4.08 92	7.68 80
wt47			7.14 108	10.31 112	5.51 79	7.98 95	2.48 112	5.79 80	5.01 99	9.48 112	5.02 67	4.55 63	5.09 112	5.88 40	4.03 54	8.03 112	2.45 70	6.44 112	5.99 57	7.30 112	2.89 81	2.38 87	7.88 111	7.43 112	8.45 112	6.37 112	4.20 85	6.59 88	8.20 112	3.68 67	8.77 112	3.26 79	7.21 112	4.09 90	4.32 22	3.69 80	6.83 80
wt48				7.77 143	6.31 75	6.93 130	3.81 132	6.69 115	7.96 134	7.83 143	6.36 101	4.70 98	4.03 142	4.06 46	3.66 89	4.63 142	2.30 101	8.10 143	4.19 89	8.67 143	2.71 112	3.21 121	7.30 141	9.60 141	7.18 143	3.95 143	7.15 120	6.91 123	7.08 143	3.61 102	9.23 133	5.42 114	7.37 143	5.31 118	5.10 57	5.18 92	6.97 79
wt4955					6.85 80	10.91 138	3.99 170	7.80 123	8.28 142	9.90 170	7.05 101	6.76 106	7.03 166	6.66 46	5.73 94	9.30 150	4.82 101	10.99 176	8.68 89	8.14 177	4.15 112	3.58 121	7.85 144	9.07 179	9.69 189	7.46 179	6.38 128	8.35 124	9.66 183	6.28 110	11.93 171	7.36 122	9.36 180	5.51 118	2.18 65	5.54 92	7.33 80
wt50						4.76 62	3.61 80	2.46 47	2.36 66	6.33 80	1.75 34	1.07 30	4.50 80	0.62 7	0.00 21	1.69 80	0.13 37	6.01 80	2.50 24	3.84 80	0.88 48	0.00 54	4.30 78	6.03 80	5.27 80	5.25 80	4.46 52	2.69 55	8.87 80	2.53 34	6.22 80	2.22 46	5.26 80	0.68 57	0.00 0	2.74 47	5.50 76
wt51							4.24 119	6.07 132	7.02 147	5.89 147	6.55 101	6.26 113	5.85 129	4.38 46	3.49 94	5.98 129	2.48 101	5.93 143	4.59 89	7.47 144	4.93 112	2.12 121	7.18 128	9.25 128	8.63 147	5.55 147	7.68 137	8.44 124	9.82 142	7.00 119	6.89 120	6.83 131	6.65 131	5.20 118	1.81 73	2.99 92	3.91 66
wt52								1.95 104	4.38 123	1.66 151	1.48 91	4.83 87	4.95 156	1.81 46	2.19 78	4.00 140	2.62 94	3.36 157	3.91 81	7.02 158	5.21 105	3.96 111	3.76 135	2.88 175	3.85 175	5.08 160	5.43 109	3.30 112	7.50 164	5.41 91	4.31 175	5.55 103	5.31 168	4.21 114	2.91 46	1.21 92	0.92 80
wt53									8.35 133	5.94 133	6.76 101	5.35 113	5.10 114	5.92 46	7.81 94	6.18 114	2.61 101	4.50 128	4.55 89	7.97 129	3.10 111	3.51 114	7.30 113	4.94 113	7.57 133	5.09 132	5.92 132	6.79 116	3.77 127	6.99 120	7.79 105	8.33 132	8.08 116	6.12 108	1.40 73	4.51 92	3.41 51
wt56										7.21 152	6.53 101	8.13 113	5.63 133	5.97 46	5.92 94	8.53 133	2.61 101	7.02 147	5.38 89	11.12 148	5.35 112	5.02 121	6.47 132	6.56 132	8.71 152	6.60 151	9.19 137	9.20 124	7.82 146	7.89 120	6.27 124	6.52 132	10.19 135	7.31 118	1.89 73	6.48 92	4.55 70
wt57											6.21 101	5.59 113	4.54 161	4.17 46	2.98 94	7.23 150	3.65 101	9.63 175	5.41 89	8.06 176	2.63 112	2.72 121	7.10 144	6.80 160	6.85 180	7.56 179	4.82 137	5.91 124	7.74 174	4.10 120	7.54 152	4.85 132	7.18 163	4.81 118	2.45 73	3.22 92	4.74 80
wt58												3.87 97	5.40 101	3.74 46	4.95 88	6.25 101	4.04 98	5.64 101	4.18 89	6.42 101	2.10 98	3.02 101	6.82 100	6.43 100	4.54 101	5.64 101	3.93 101	4.74 101	2.74 101	3.98 101	5.29 92	5.95 101	4.50 101	5.75 95	3.64 56	2.99 79	2.10 38
wt59													4.95 97	3.31 46	3.69 94	5.73 97	3.33 94	4.03 111	5.30 89	9.18 112	6.95 94	4.26 97	5.01 96	4.37 96	7.05 113	5.54 113	7.13 113	8.37 99	5.23 110	6.88 113	5.30 88	5.94 113	9.57 99	4.35 91	1.73 72	3.83 75	2.58 34
wt60														5.64 46	4.06 88	6.96 150	3.94 101	6.81 166	4.95 89	7.08 166	4.28 112	2.39 121	6.89 144	6.13 165	6.63 166	5.99 166	4.61 119	4.46 122	6.74 166	4.99 101	6.70 157	5.63 113	5.62 166	3.88 118	2.67 56	2.15 92	2.08 80
wt61															3.80 46	6.11 46	2.51 46	3.74 46	4.52 46	3.65 46	2.76 46	2.73 46	5.49 46	5.84 46	4.21 46	3.30 46	3.84 46	6.67 46	3.82 46	3.05 46	5.16 46	3.59 46	4.76 46	3.47 46	4.32 28	5.24 46	0.36 11
wt62																6.57 88	1.81 85	4.22 94	2.43 86	5.28 94	2.10 85	4.35 88	4.50 87	2.55 87	3.66 94	3.56 94	3.48 94	3.98 90	2.49 94	4.99 94	5.87 79	4.45 94	5.48 90	4.72 82	1.68 62	5.37 66	1.89 25
wt63																	3.05 101	6.79 150	5.33 89	8.32 150	5.23 112	3.87 121	7.72 144	6.29 149	6.59 150	8.12 150	5.94 119	7.22 122	5.49 150	4.85 101	7.47 141	5.00 113	8.16 150	7.02 118	3.88 56	5.26 92	3.56 80
wt64																		2.16 101	6.20 88	4.39 101	3.97 101	2.59 101	2.70 101	3.64 101	2.52 101	2.40 101	2.69 101	3.01 101	2.48 101	2.11 98	2.19 95	4.70 101	2.23 101	3.46 98	2.45 53	1.46 82	0.17 41
wt656																			4.53 89	6.81 181	3.80 112	1.64 121	6.26 144	7.83 166	8.67 181	8.51 181	5.53 133	6.26 124	7.80 180	3.83 115	10.17 158	6.20 127	8.39 169	5.42 118	1.74 70	3.99 92	5.63 80
wt67																				5.79 89	5.90 88	3.79 89	3.64 89	4.54 89	4.61 89	3.77 89	6.25 89	6.14 89	4.59 89	4.88 89	4.99 82	4.57 89	4.23 89	4.14 85	2.25 54	4.61 69	3.50 28
wt7086																					7.13 112	5.21 121	7.38 144	7.21 167	8.44 183	10.30 183	12.05 134	9.86 124	9.42 181	9.62 116	7.02 159	9.19 128	11.69 170	8.74 118	2.09 71	3.56 92	3.35 80
wt68																						2.62 112	1.95 112	4.15 112	6.08 112	3.69 112	6.69 112	5.45 112	5.16 112	5.86 98	3.44 106	5.66 110	5.41 112	3.98 109	1.60 53	2.51 92	2.27 52
wt69																							1.73 120	2.42 120	2.53 121	2.66 121	5.43 119	2.75 121	2.21 121	3.38 101	2.36 112	2.56 113	4.74 121	6.72 115	2.75 56	2.90 92	0.00 58
wt71																								8.69 144	7.39 144	9.02 144	4.15 118	7.32 121	6.63 144	4.56 100	7.97 136	6.20 112	6.77 144	6.48 118	3.06 55	2.70 92	3.55 80
wt72																									9.17 195	7.02 169	6.74 118	5.50 121	8.63 173	5.18 100	9.62 192	6.41 112	6.05 177	5.21 118	5.17 55	3.33 92	5.30 80
wt73																										7.42 188	7.90 137	8.11 124	10.25 187	7.62 120	9.50 187	6.73 132	9.35 180	4.76 118	0.85 73	3.92 92	6.26 80
wt74																											4.38 137	5.26 124	8.73 183	5.12 119	7.86 161	7.65 131	7.12 172	5.15 118	1.38 73	2.81 92	2.57 80
wt76																												9.87 121	8.54 132	8.03 119	4.45 110	6.24 131	8.22 121	5.31 113	1.89 73	3.59 92	3.61 56
wt77																													7.30 124	5.97 103	5.80 113	6.70 115	7.32 124	5.25 116	2.05 58	3.85 92	4.75 59
wt78																														5.16 114	8.58 165	7.15 126	7.77 176	3.67 118	2.61 69	3.77 92	5.19 80
wt79																															5.69 92	6.30 120	5.41 103	4.09 95	1.95 73	2.19 79	0.60 38
wt81																																5.83 104	8.74 169	5.20 115	3.89 47	5.73 92	8.39 80
wt83																																	4.11 115	4.89 107	2.03 73	2.64 91	1.69 50
wt84																																		7.96 118	3.05 58	4.91 92	5.12 80
wt87																																			2.62 50	3.54 92	1.90 61
wt88																																				2.24 34	0.00 0
wt89																																					3.87 51

Table 33: Ring-width data for site master curve **WHTOWR5**, AD 1260–1489. Main roof reconstruction, 230 rings, starting date AD 1260

ring widths (0.01mm)

196	215	199	180	299	248	283	217	248	357
380	315	247	425	392	216	147	168	166	198
313	266	274	313	237	279	233	187	143	189
179	219	274	363	370	253	290	250	255	288
249	244	292	170	207	207	200	249	293	262
230	175	244	164	225	252	246	265	223	245
255	261	262	244	190	136	112	173	176	182
173	112	128	151	216	218	150	133	158	228
210	189	160	159	161	237	227	185	195	160
141	208	154	180	146	145	170	211	132	175
172	139	195	219	220	174	158	165	175	211
211	157	176	165	193	172	198	169	207	195
175	165	181	149	138	184	191	180	210	167
130	125	108	141	143	156	160	138	176	191
175	163	155	164	191	151	193	143	194	175
140	142	146	132	127	116	121	127	130	103
166	153	130	164	145	121	94	112	148	146
125	118	169	126	120	134	110	128	134	129
129	125	142	144	153	129	136	131	139	129
130	129	113	117	124	133	131	121	108	95
98	105	113	137	100	148	128	109	110	123
135	109	126	118	115	139	120	104	102	164
137	163	140	125	130	119	124	130	122	158

number of samples in master

1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	2	2	2	2	2
2	2	2	2	2	2	3	3	3	3
3	4	4	5	5	5	5	7	7	7
7	8	8	9	10	11	12	12	12	12
13	13	13	13	13	13	13	13	13	13
13	14	14	14	15	16	17	17	18	19
19	19	19	19	19	19	19	19	20	20
20	20	21	21	21	21	21	22	22	23
23	23	24	24	24	24	25	27	28	28
28	28	28	28	28	28	28	29	29	29
31	31	31	31	32	32	32	32	32	32
33	33	33	34	34	34	34	34	34	34
34	34	34	34	34	34	34	35	35	35
35	35	35	35	34	34	34	34	33	33
33	33	33	33	33	34	34	34	34	34
34	34	34	34	34	34	34	34	34	34
34	34	34	34	34	34	34	33	33	33
33	33	33	32	32	32	32	32	32	31
31	31	31	31	31	31	31	31	31	31
31	29	29	28	28	27	27	27	25	24
22	19	18	16	16	16	16	15	15	15
14	14	14	14	13	12	11	10	9	6

Table 34: Dating of **WHTOWR5** against reference chronologies at AD 1489

Reference chronology	Spanning	Overlap	*t*-value
SOMRST04 *(Miles unpubl)*	770–1979	230	9.71
OXON93 *(Haddon-Reece et al 1993)*	632–1987	230	9.85
KENT88 *(Laxton and Litton 1989)*	1158–1540	230	10.35
NEWDIG1 *(Bridge 1998a)*	1261–1483	223	10.86
HANTS02 *(Miles 2003)*	443–1972	230	11.24
ANGLIA01 *(Bridge pers comm)*	944–1789	230	11.43
FULHAM1 *(Bridge and Miles 2004)*	1356–1494	134	12.81
SENG98 *(Bridge 1998b)*	944–1790	230	13.80
LONDON *(Tyers pers comm)*	413–1728	230	15.41

Chronologies in **bold** denote regional masters

Table 35: Matrix of *t*-values and overlaps for components of **wt101**

Sample:	**tol101b**	**tol101c**
Relative last ring date:	39	45
tol101a	5.09 31	8.12 37
	tol101b	4.90 33

Table 36: Matrix of *t*-values and overlaps for components of **wt1004**

Sample:	**wt101**	**wt102**	**wt103**	**wt104**
Relative last ring date:	1065	1056	1065	1061
wt100	5.24 40	3.05 48	5.53 51	4.68 58
	wt101	2.36 36	4.75 45	4.01 41
		wt102	4.20 47	3.38 48
			wt103	6.93 52

Table 37: Matrix of *t*-values and overlaps for components of **WHTOWR6**

Sample:	**wt92**	**wt93**	**wt94**	**wt95**	**wt96**	**wt97**	**wt98**	**wt105**	**wt106**
Last ring date AD:	1531	1504	1532	1531	1528	1495	1508	1513	1531
wt91	0.82 49	2.42 84	4.23 91	2.61 83	2.10 45	2.66 87	3.44 99	3.57 95	1.24 57
	wt92	0.82 48	1.00 75	2.20 75	0.79 68	2.91 39	3.10 52	1.28 57	0.86 75
		wt93	2.11 84	3.07 82	1.63 44	2.68 75	6.21 84	2.89 84	2.48 56
			wt94	3.90 109	1.47 68	4.12 81	1.69 94	3.72 99	2.11 83
				wt95	1.61 68	4.91 73	2.83 86	4.07 91	5.08 83
					wt96	2.89 35	3.72 48	3.78 53	2.03 68
						wt97	3.84 87	4.12 85	2.22 47
							wt98	4.89 98	3.16 60
								wt105	4.46 65

Table 38: Ring-width data for site master curve **WHTOWR6**, AD 1370–1532. Turret repairs, 163 rings, starting date AD 1370

ring widths (0.01mm)

287	280	242	197	162	147	178	154	235	215
202	213	190	210	168	216	268	209	202	133
123	133	108	177	175	185	177	114	134	166
131	145	109	169	142	93	140	558	450	416
270	425	343	261	245	205	201	222	266	208
311	263	217	217	208	200	152	175	188	175
167	202	281	164	156	175	173	153	146	104
118	136	151	140	150	119	107	124	131	149
158	180	141	119	150	139	151	123	147	124
139	144	134	176	111	160	168	152	144	136
125	101	125	130	149	168	129	98	107	122
145	177	147	130	125	120	135	153	148	142
143	123	106	114	131	122	138	112	94	102
102	101	95	100	113	105	116	127	131	135
135	123	137	128	152	150	121	99	90	103
99	116	158	138	123	99	105	108	123	108
107	159	156							

number of samples in master

1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	2	2	3
3	4	4	4	4	5	5	5	5	5
5	6	6	7	7	7	7	7	7	7
7	7	7	7	7	7	7	7	7	7
7	7	7	7	7	7	7	7	7	8
8	8	8	8	8	8	8	9	9	9
9	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	9	9	9	9
9	9	9	9	9	8	7	7	7	6
6	6	6	6	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	4
4	4	1							

Table 39: Dating of **WHTOWR6** against reference chronologies at AD 1532

Reference chronology	Spanning	Overlap	*t*-value
SOMRST04 *(Miles unpubl)*	770–1979	163	6.85
LONDON *(Tyers pers comm)*	413–1728	163	6.96
HANTS02 *(Miles 2003)*	443–1972	163	7.08
SOUTH *(Hillam and Groves 1994)*	406–1594	163	7.10
SENG98 *(Bridge 1998b)*	944–1790	163	7.21
SARUM11 *(Miles 2005b)*	1409–1541	124	7.87
CHAWTON3 *(Miles and Worthington 1998)*	1446–1582	127	7.92
OXON93 *(Haddon-Reece et al 1993)*	632–1987	163	8.23
GREYSCT2 *(Miles et al 2004)*	1417–1587	116	8.30
MAYTREE *(Miles and Worthington 2000)*	1413–1559	120	9.42

Chronologies in **bold** denote regional masters

Table 40: Matrix of *t* -values and overlaps for components of **wt111**

Sample:	**wt111b**	**wt111c**
Last ring date AD:	1549	1587
wt111a	5.03 55	11.24 93
	wt111b	5.60 57

Table 41: Matrix of *t* -values and overlaps for components of **WHTOWR7**

Sample: *Last ring date AD:*	**wt108** 1578	**wt109** 1601	**wt110** 1591	**wt111** 1591	**wt112** 1600	**wt113** 1602	**wt116** 1602	**wt117** 1602	**wt118** 1601	**wt119** 1602	**wt121** 1602	**wt122** 1602	**wt124** 1602	**wt125** 1602	**wt127** 1602	**wt128** 1616	**wt129** 1616	**wt130** 1599
wt107	3.02 69	4.61 46	3.27 75	2.22 73	5.04 45	5.77 62	1.37 83	4.04 50	1.72 83	2.81 48	5.14 10	5.90 46	1.99 83	3.07 83	4.93 77	6.93 44	3.33 46	4.67 49
	wt108	4.42 59	4.26 82	5.50 82	1.89 58	4.69 75	3.82 82	3.37 63	3.62 82	3.66 61	1.81 23	6.61 59	4.01 82	2.31 82	3.61 82	5.87 57	4.17 59	3.12 62
		wt109	5.17 72	4.27 72	3.92 80	7.92 82	1.67 82	5.93 82	5.52 82	5.96 82	3.33 46	6.90 82	3.60 82	3.00 82	5.32 82	6.84 80	4.64 82	4.54 80
			wt110	4.36 99	3.62 71	4.23 88	3.76 101	4.51 76	3.98 101	3.69 74	3.08 36	6.41 72	5.00 101	2.60 101	4.18 101	5.19 70	3.86 72	5.32 75
				wt111	3.33 71	3.92 88	4.89 99	2.83 76	5.10 99	5.91 74	2.11 36	5.26 72	3.02 99	2.33 99	4.07 99	3.80 70	2.18 72	4.08 75
					wt112	3.77 80	2.52 80	1.43 80	1.99 80	3.75 80	1.47 45	2.68 80	1.90 80	2.77 80	3.98 80	3.99 79	3.39 80	5.10 79
						wt113	2.84 99	4.43 87	6.48 98	4.16 85	1.76 47	5.45 83	4.76 99	3.69 99	5.36 99	5.94 81	3.24 83	4.29 83
							wt116	0.75 87	1.69 128	1.51 85	2.35 47	2.27 83	5.95 123	3.27 129	5.61 114	2.26 81	1.79 83	1.73 83
								wt117	4.91 86	3.54 85	3.43 47	7.69 83	3.79 87	3.88 87	1.45 87	4.31 81	2.91 83	2.71 83
									wt118	3.43 84	2.12 46	5.65 82	3.20 122	1.88 130	1.87 113	2.73 80	3.21 82	3.52 83
										wt119	3.55 47	6.85 83	3.65 85	2.92 85	4.34 85	5.93 81	3.35 83	5.94 82
											wt121	5.87 47	3.97 47	1.01 47	0.86 47	2.47 47	4.63 47	3.39 44
												wt122	5.23 83	2.89 83	3.74 83	8.34 81	4.99 83	6.86 80
													wt124	3.40 123	4.68 114	2.79 81	3.97 83	2.39 83
														wt125	2.33 114	3.02 81	1.14 83	2.65 83
															wt127	6.62 81	3.21 83	3.72 83
																wt128	4.92 95	7.72 78
																	wt129	3.73 80

Table 42: Ring-width data for site master curve **WHTOWR7**, AD 1463–1616. Elizabeth I and James I alterations, 154 rings, starting date AD 1463

ring widths (0.01mm)

408	288	247	243	207	224	280	232	258	323
233	280	385	303	297	294	323	288	317	250
236	230	207	214	303	298	308	278	209	226
212	214	237	285	229	160	184	172	179	183
205	204	219	175	189	179	208	185	226	240
231	215	230	222	201	254	238	184	221	225
211	222	202	258	233	237	212	199	260	186
192	187	273	220	222	211	238	205	214	148
181	166	212	163	139	186	225	171	187	143
180	177	210	164	146	146	185	191	170	217
176	179	142	139	156	191	225	221	199	165
155	151	135	146	164	128	174	210	176	158
160	184	191	205	185	163	203	145	192	190
184	224	206	186	182	183	148	162	157	143
179	196	127	203	163	174	126	121	104	106
133	104	112	134						

number of samples in master

1	1	1	1	1	1	1	1	1	2
2	3	3	3	3	3	3	4	4	4
5	5	5	5	5	5	6	6	7	7
8	8	8	8	9	9	9	9	9	9
9	10	10	10	10	10	10	10	10	10
10	10	10	11	12	13	13	16	17	18
18	18	18	18	18	18	18	18	18	18
18	18	18	18	18	18	18	18	18	18
18	18	18	18	18	18	18	18	18	18
18	18	18	19	19	19	19	19	19	19
19	19	19	18	18	18	18	18	18	18
18	18	18	18	18	18	17	17	17	17
17	17	17	17	17	17	17	17	17	15
15	15	15	15	15	15	15	14	13	11
2	2	2	2	2	2	2	2	2	2
2	2	2	2						

Table 43: Dating of **WHTOWR7** (AD 1463–1616) against reference chronologies at AD 1616

Reference chronology	Spanning	Overlap	*t*-value
BDLEIAN4 *(Miles and Worthington 1999)*	1436–1570	108	10.40
OXON93 *(Haddon-Reece et al 1993)*	632–1987	154	10.64
SALOP95 *(Miles 1995)*	881–1745	154	10.94
LONDON *(Tyers pers comm)*	413–1728	154	10.93
COBHSQ01 *(Arnold et al 2003)*	1317–1662	154	11.09
SENG98 *(Bridge 1998b)*	944–1790	154	11.49
EASTMID *(Laxton and Litton 1988)*	882–1981	154	11.58
WC KITCH *(Hillam and Groves 1996)*	1331–1573	111	12.46
HANTS02 *(Miles 2003)*	443–1972	154	12.95
ANGLIA01 *(Bridge pers comm)*	944–1789	154	14.12

Chronologies in **bold** denote regional masters

Table 44: Matrix of *t* -values and overlaps for components of **WHTOWR8**

Sample:	**wt132**	**wt134**	**wt135**	**wt136**	**wt137**
Last ring date AD:	1732	1732	1714	1732	1732
wt131	3.06	3.40	4.72	4.63	4.96
	43	43	43	43	37
wt132		2.26	3.41	4.26	3.12
		66	59	65	59
wt134			3.46	6.07	6.84
			48	65	59
wt135				5.65	4.43
				47	41
wt136					3.41
					59

Table 45: Ring-width data for site master curve **WHTOWR8**, AD 1645–1732. George II insertion of basement vaults, 88 rings, starting date AD 1645

ring widths (0.01mm)

83	204	180	181	174	209	202	155	161	204
193	241	244	245	290	300	319	327	294	229
203	306	234	308	281	320	314	275	320	250
282	316	416	368	357	404	378	414	310	254
270	284	235	253	308	273	334	228	252	231
162	149	225	297	253	235	206	130	178	235
187	187	173	142	144	109	137	177	186	151
163	199	198	134	138	147	196	185	163	161
126	187	181	150	204	188	232	183		

number of samples in master

1	1	1	1	1	1	1	1	1	1
1	2	2	2	2	2	2	2	2	2
2	2	3	5	5	5	5	5	5	6
6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	6	5	5	5	5
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4		

Table 46: Dating of **WHTOWR8** against reference chronologies at AD 1732

Reference chronology	**Spanning**	**Overlap**	***t*-value**
SARUMBP8 *(Miles and Worthington 2000)*	1616–1735	88	4.72
STOWE6 *(Miles et al 2003)*	1610–1762	88	4.89
SARUM6 *(Miles 2005b)*	1577–1719	75	4.90
mfa25 *(Miles 1996)*	1672–1734	61	4.95
STOWE1 *(Miles and Worthington 1998)*	1610–1751	88	5.00
THEHOVEL *(Miles and Worthington 1999)*	1671–1811	62	5.12
CHAWTON *(Oxford unpubl)*	1289–1772	88	5.13
CBMASQ02 *(Howard et al 2003)*	1595–1727	83	5.77
SARUM7 *(Miles 2002)*	1672–1735	61	6.42
HWC10 *(Bridge 2000)*	1684–1739	49	7.64

Chronologies in **bold** denote regional masters

Table 47: Matrix of *t* -values and overlaps for components of **wt139**

Sample:	**wt139b**	**wt139c**
Last ring date AD:	1721	1780
wt139a	5.65 22	6.05 39
	wt139b	0.00 0

Table 48: Matrix of *t* -values and overlaps for components of **WHTOWR9**

Sample:	**wt139**	**wt141**	**wt142**	**wt145**	**wt146**	**wt147**	**wt148**	**wt150**	**wt151**	**wt152**	**wt153**	**wt154**	**wt155**
Last ring date AD:	1780	1778	1779	1780	1776	1770	1779	1780	1780	1782	1782	1782	1782
wt138	2.48 / 78	2.36 / 76	2.88 / 77	2.61 / 59	2.63 / 74	5.19 / 68	4.68 / 77	3.27 / 78	4.16 / 71	5.00 / 78	2.74 / 50	1.25 / 55	1.85 / 50
wt139		1.65 / 83	2.78 / 84	0.58 / 59	1.42 / 81	3.60 / 75	3.64 / 80	5.49 / 85	4.91 / 71	3.87 / 85	2.89 / 50	2.75 / 55	1.68 / 50
wt141			5.29 / 99	0.10 / 57	4.67 / 98	2.50 / 83	2.75 / 79	2.43 / 85	2.16 / 69	1.58 / 89	0.00 / 48	0.00 / 53	1.20 / 48
wt142				3.14 / 58	3.57 / 97	3.63 / 83	4.54 / 80	4.27 / 86	3.01 / 70	2.63 / 90	1.45 / 49	0.73 / 54	1.82 / 49
wt145					0.53 / 55	1.79 / 49	1.27 / 58	3.77 / 59	3.69 / 59	5.01 / 59	3.90 / 50	2.13 / 55	3.52 / 50
wt146						0.63 / 83	2.47 / 77	2.24 / 83	1.38 / 67	3.60 / 87	2.01 / 46	1.03 / 51	1.13 / 46
wt147							3.23 / 71	6.05 / 77	4.46 / 61	2.76 / 81	1.45 / 40	0.87 / 45	1.96 / 40
wt148								3.33 / 80	2.07 / 70	3.34 / 80	0.76 / 49	0.15 / 54	0.00 / 49
wt150									5.76 / 71	5.04 / 87	3.69 / 50	3.26 / 55	2.89 / 50
wt151										3.68 / 71	2.84 / 50	3.09 / 55	3.62 / 50
wt152											6.28 / 52	5.38 / 57	3.63 / 52
wt153												4.00 / 52	6.02 / 52
wt154													2.59 / 52

Table 49: Ring-width data for site master curve **WHTOWR9**, AD 1629–1782. George III repairs to turrets, 154 rings, starting date AD 1629

ring widths (0.01mm)

83	73	139	73	59	58	90	164	94	93
141	168	216	232	224	211	179	195	288	483
243	283	160	160	140	155	243	144	172	203
154	197	225	254	342	260	226	248	156	202
192	158	193	183	294	188	232	170	155	183
375	333	302	311	223	150	125	147	142	171
137	196	222	198	194	213	183	182	181	205
160	193	197	202	321	275	203	251	249	244
263	244	253	253	297	192	240	244	271	215
165	192	249	230	176	222	203	255	257	222
231	199	201	228	207	241	242	218	222	276
258	197	138	107	132	138	174	214	206	186
162	208	223	208	187	192	184	177	172	184
187	149	178	127	182	171	141	170	200	234
186	188	158	162	177	198	174	177	177	178
170	174	173	219						

number of samples in master

1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
2	3	3	3	3	3	3	3	3	4
4	5	5	5	5	6	6	7	7	7
7	8	8	8	9	9	9	9	9	9
9	10	10	10	10	10	10	10	10	10
10	10	10	11	11	11	11	12	12	12
12	12	14	14	14	14	14	14	14	14
14	14	14	14	14	14	14	14	14	14
14	14	14	14	14	14	14	14	14	14
14	14	14	14	14	14	14	14	14	14
14	14	13	13	13	13	13	13	12	12
11	9	4	4						

Table 50: Dating of **WHTOWR9** against reference chronologies at AD 1782

Reference chronology	Spanning	Overlap	*t*-value
OXON93 *(Haddon-Reece et al 1993)*	632–1987	154	5.82
MDM24 *(Miles et al 2003)*	1666–1774	111	5.90
HANTS02 *(Miles 2003)*	443–1972	154	6.00
HWC10 *(Bridge 2000)*	1684–1739	49	7.64
CRMASQ01 *(Arnold et al 2004)*	1639–1753	115	6.18
BRNGHST1 *(Groves et al 2004)*	1664–1781	118	6.12
BASINGDF *(Bridge 1996)*	1684–1788	99	6.54
HAILSHAM *(Bridge 2005)*	1711–1813	72	6.69
PTSTONE1 *(Miles et al 2004)*	1729–1823	54	6.64

Chronologies in **bold** denote regional masters

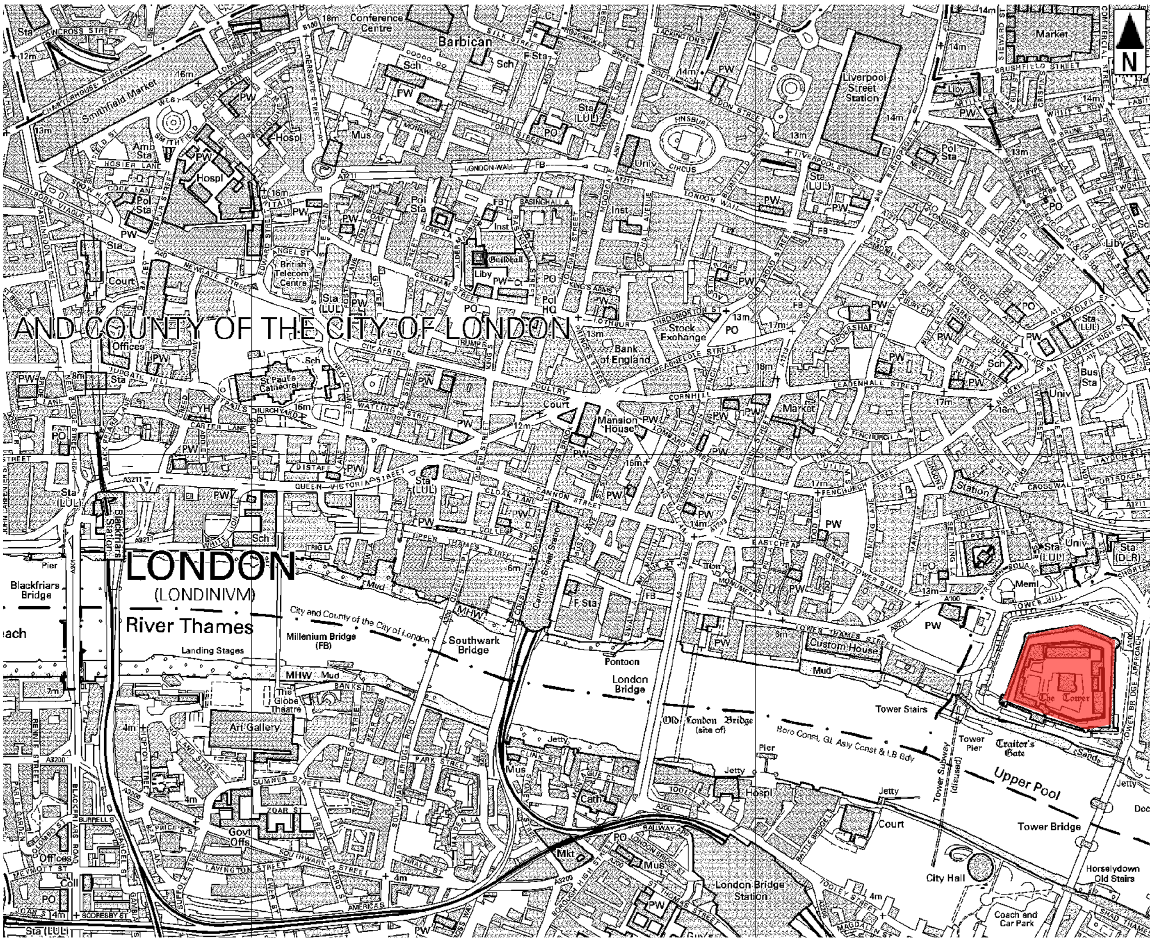


Figure 1: Map of central London showing the location of the Tower of London.

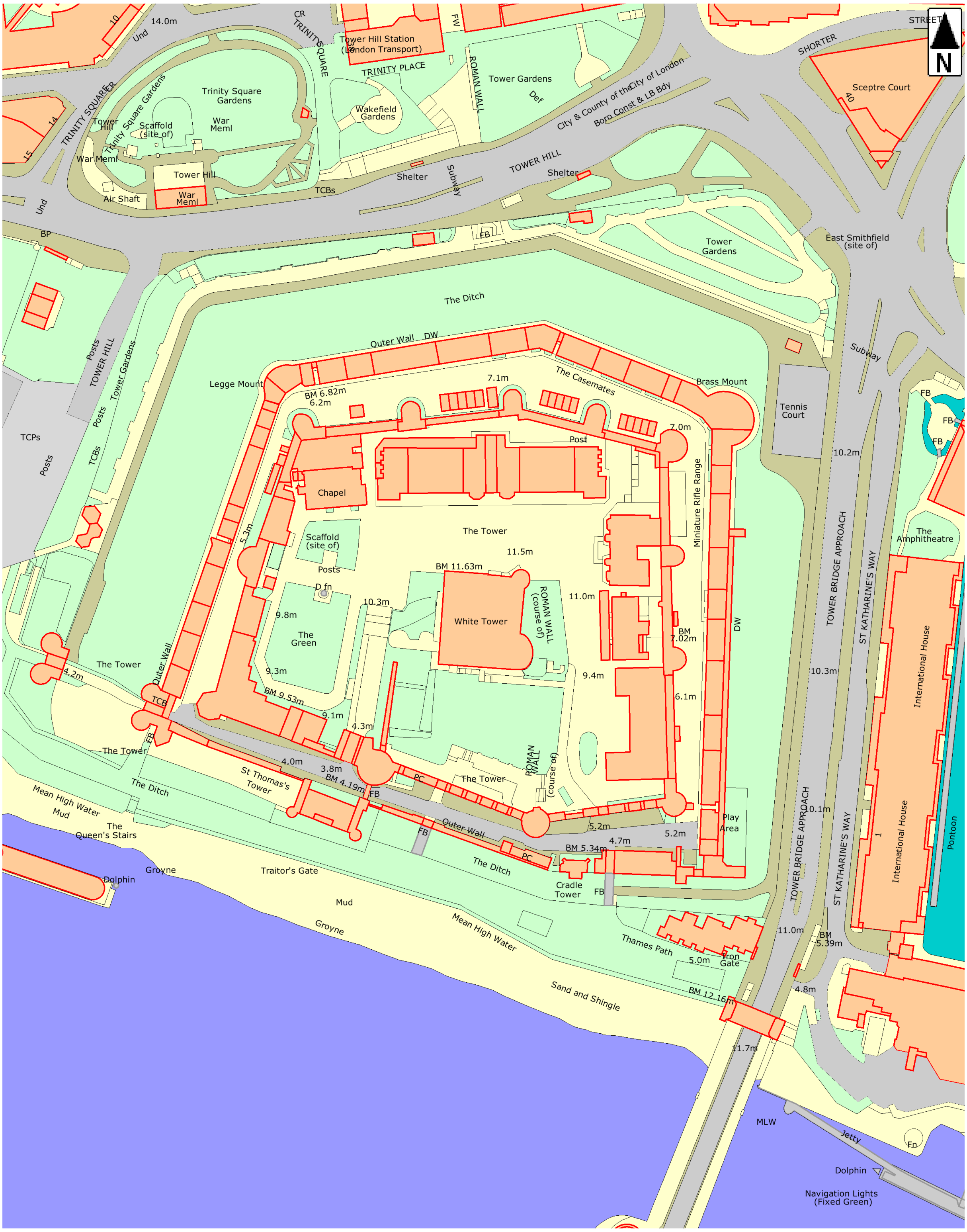


Figure 2: Plan of the Tower of London, showing the location of the White Tower.

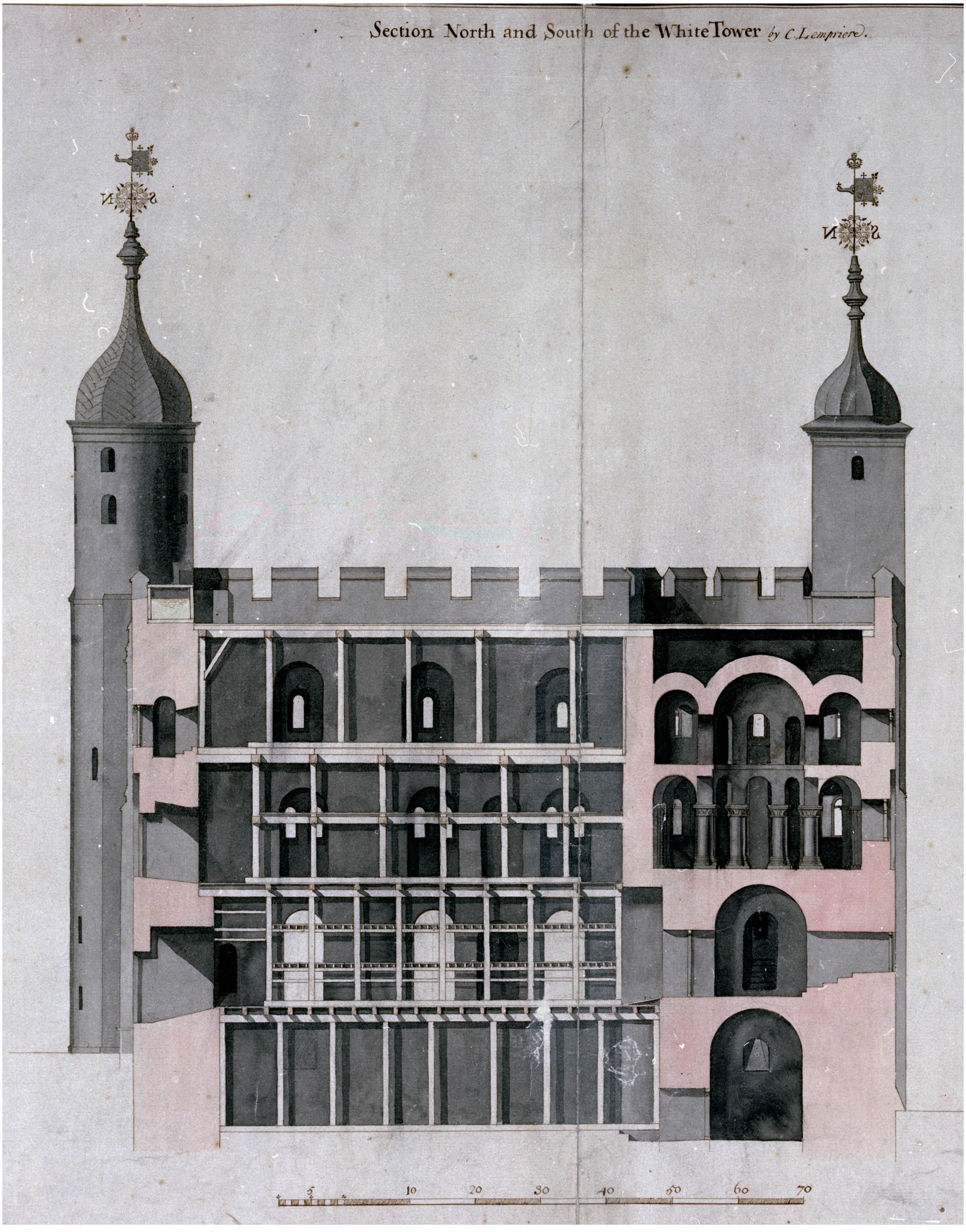


Figure 3: North-south section of the White Tower by Lemprière in 1729 (TNA WORK31/89, copyright The National Archives)

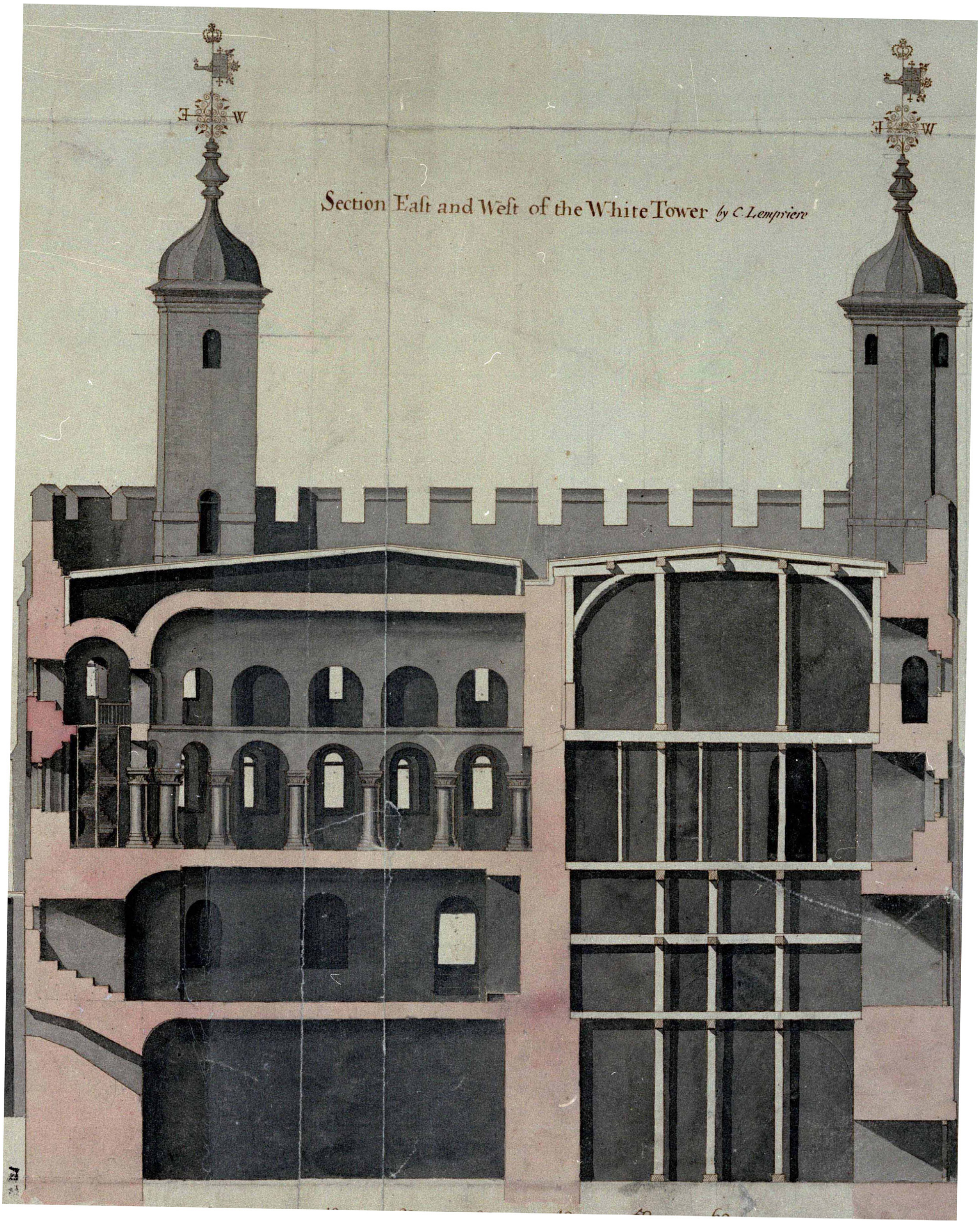


Figure 4: East-west section of the White Tower by Lemprière in 1729 (TNA WORK31/90, copyright The National Archives)

Figure 5: Photograph of the Chapel of St John by Dr John Crook (info@john-crook.com)

Figure 6: Door at bottom of Great Vice (*c* 1475)

Figure 7: Door at south end of east basement room (*c* 1350)

Figure 8: Drawbar socket in ground-floor spine wall (**wt15**–**wt18**)

Figure 9: Door jamb and drawbar socket on west side of ground-floor entrance

Figure 10: Detail of drawbar socket on west side of ground-floor entrance (**wt08–wt14**)

Figure 11: First-floor lintel over cupboard recess in north-west embrasure (**wt19**)

Figure 12: First-floor lintel over cupboard recess in south-east embrasure showing redundant peg hole

Figure 13: Section of drain at second-floor level, west side

Figure 14: Fragments of drain at second-floor level, west side (**wt23**)

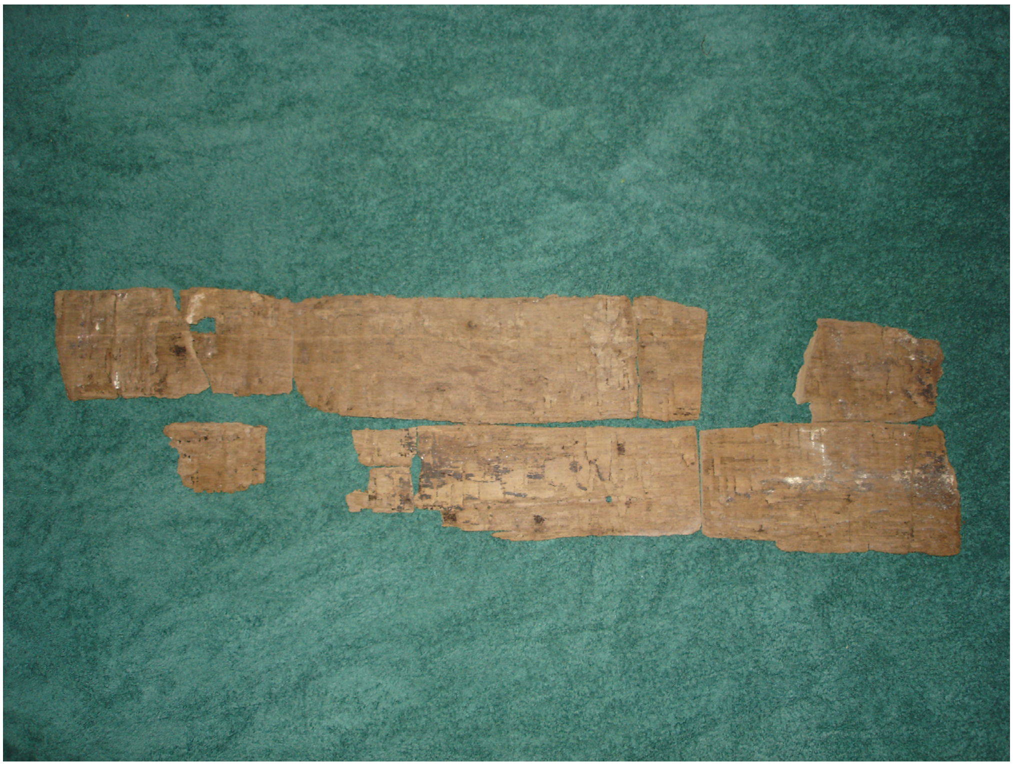


Figure 15: Photograph of board found in drain at second-floor level, east side (**wt22**)

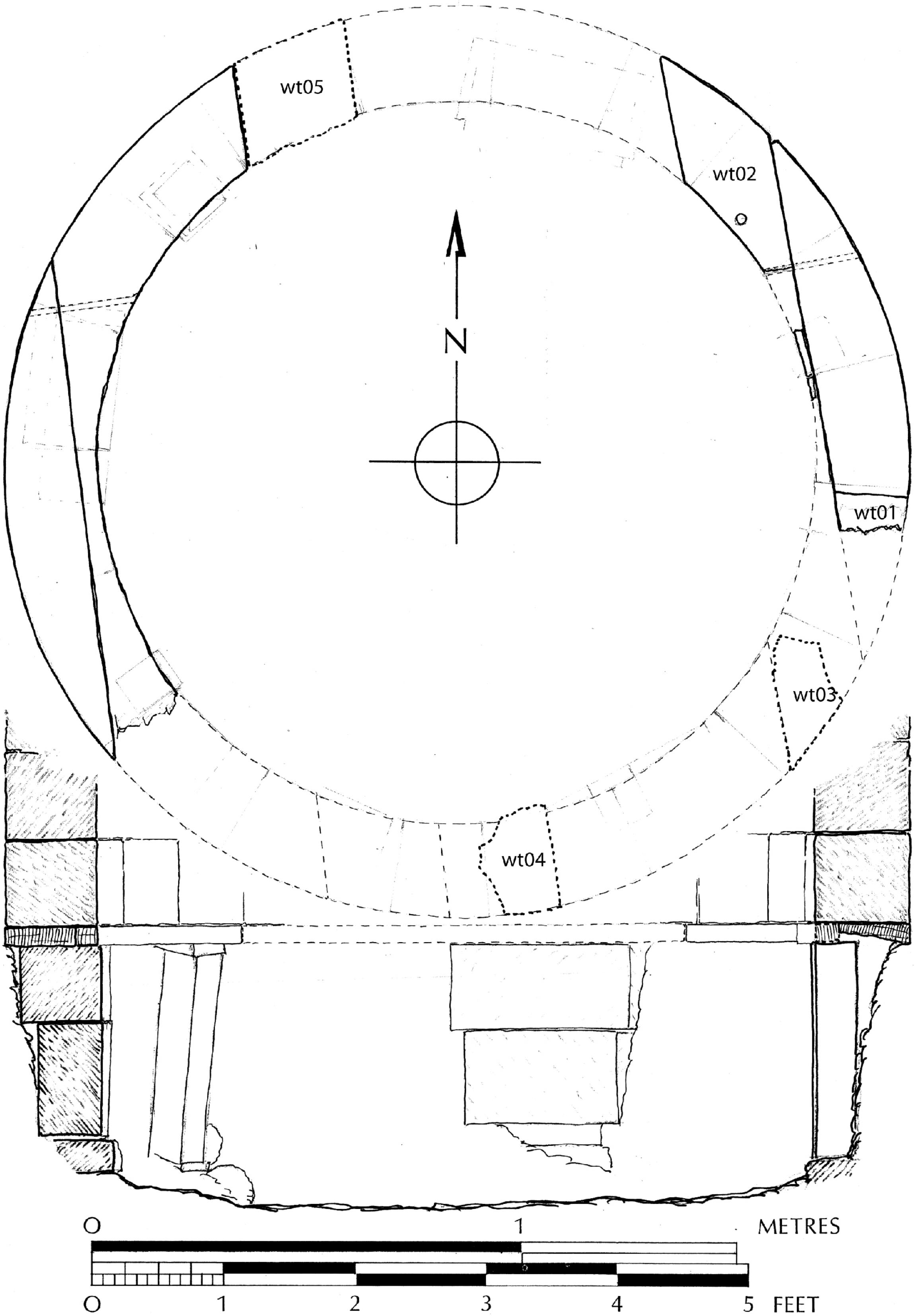


Figure 16: Plan and section of beech template at bottom of well

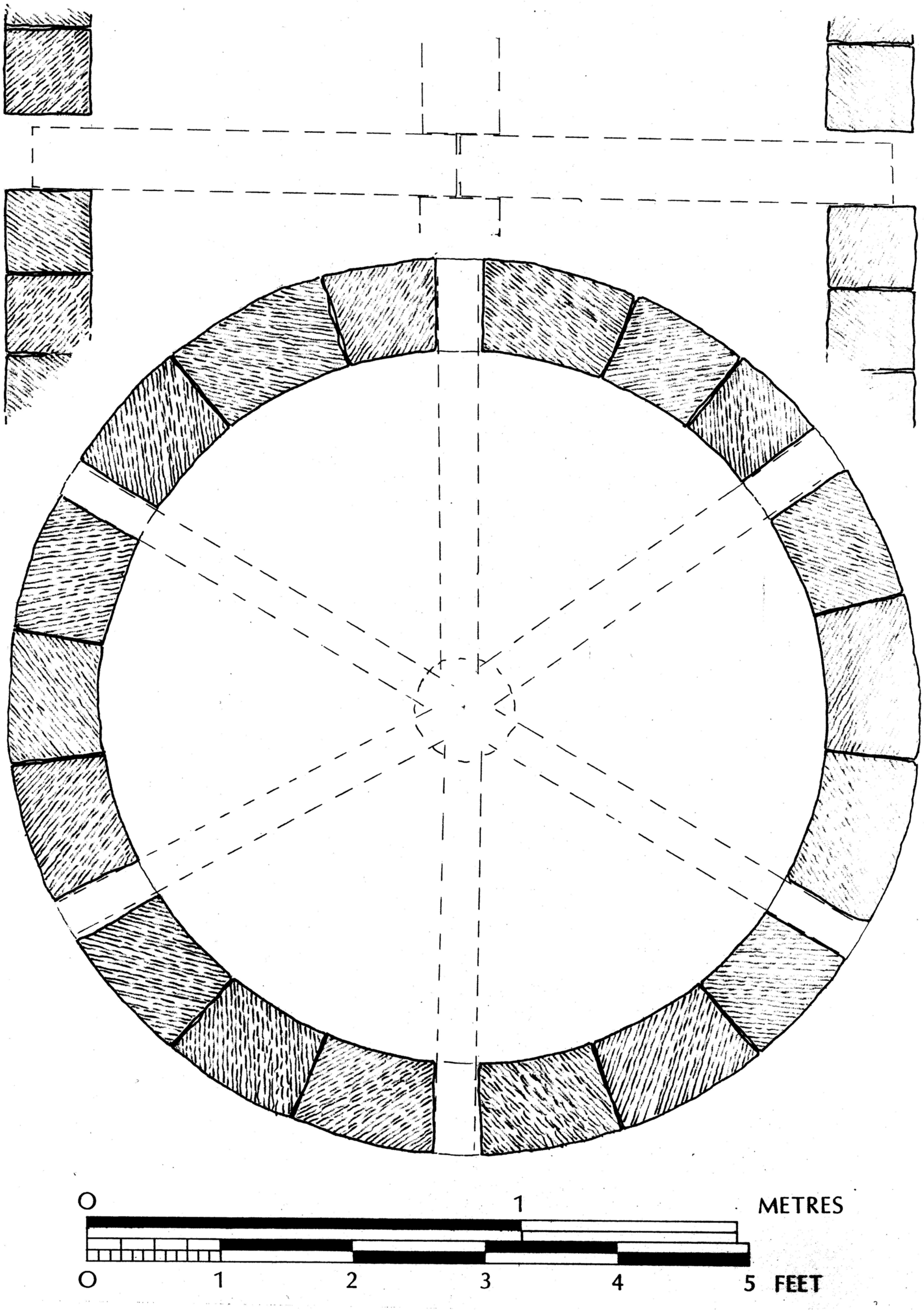
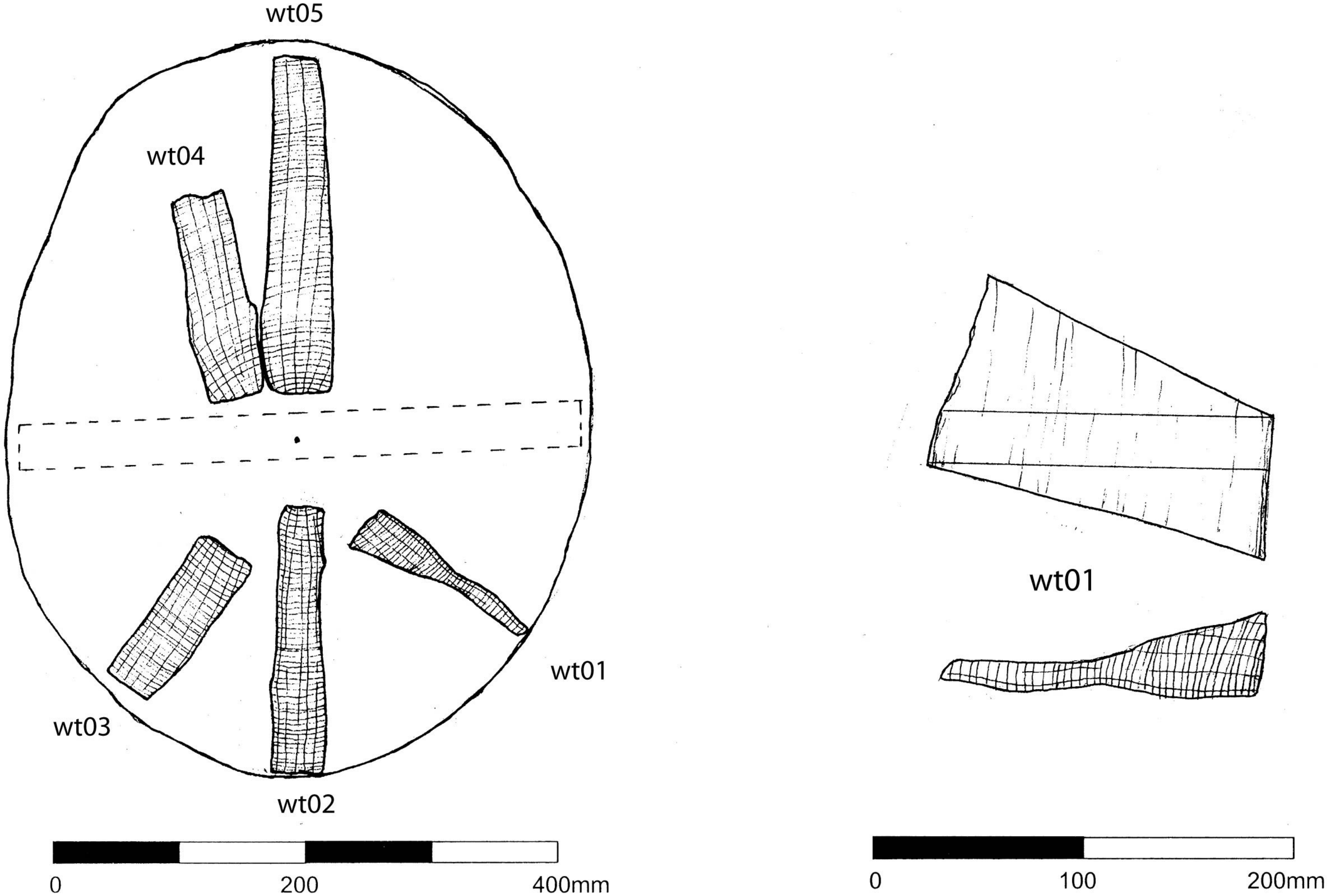


Figure 17: Part section and plan of stone well lining showing putlog holes, with removed putlogs and centre post shown in broken lines



Possible method of conversion of beech planks

Figure 18: Plans and sections of beech recovered from bottom of well

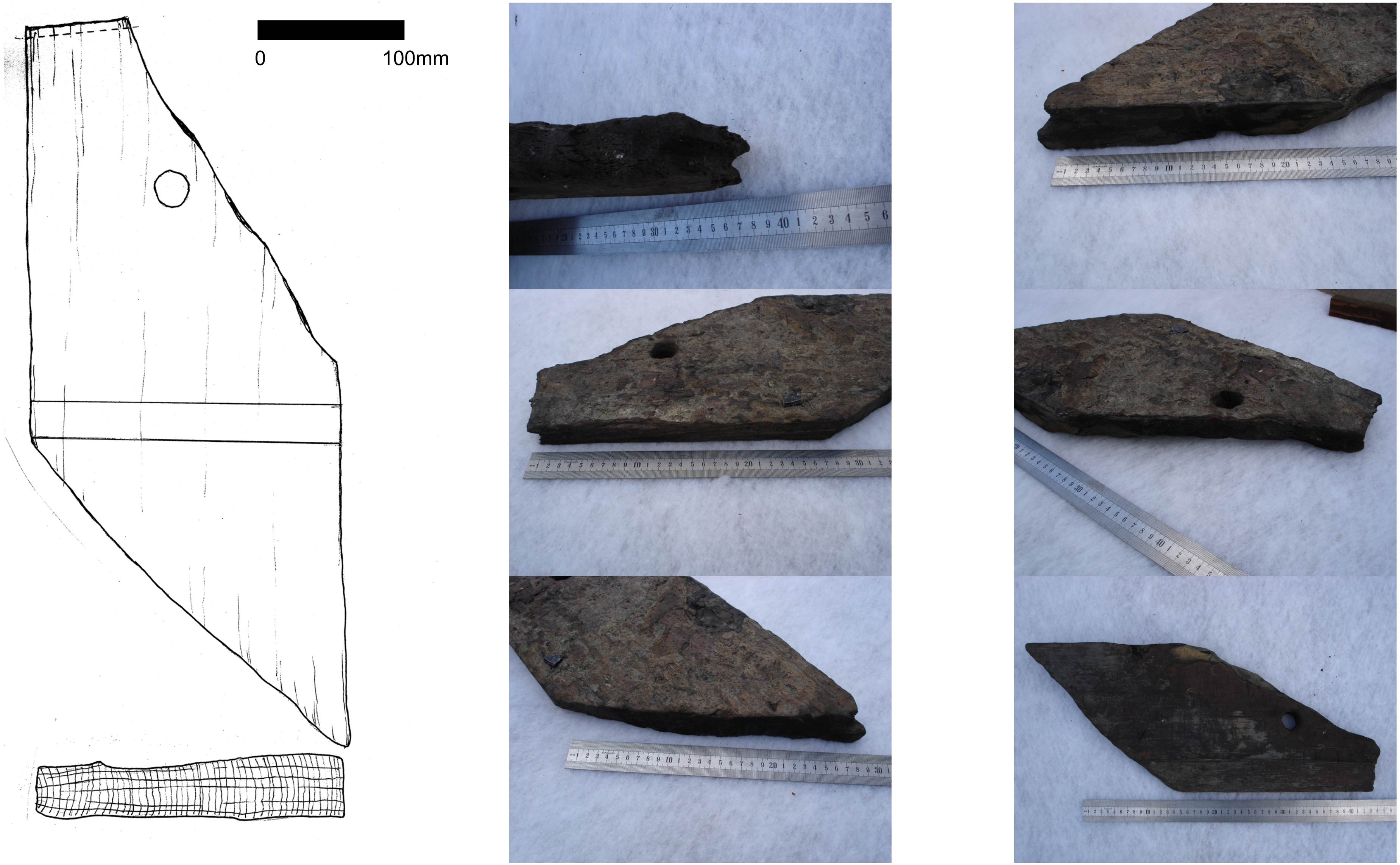
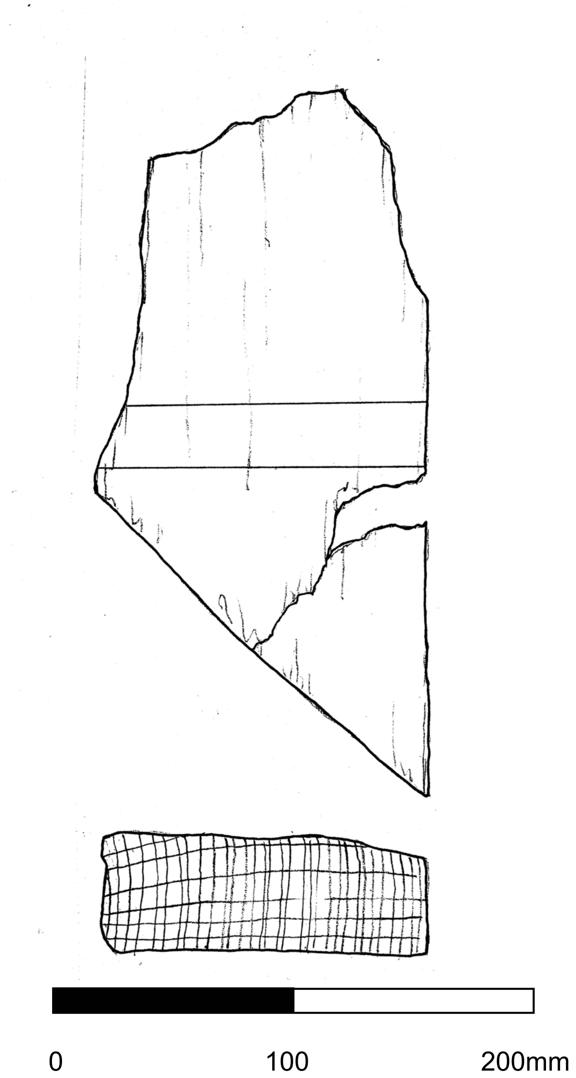


Figure 19: Beech plank from the well (**wt02**)



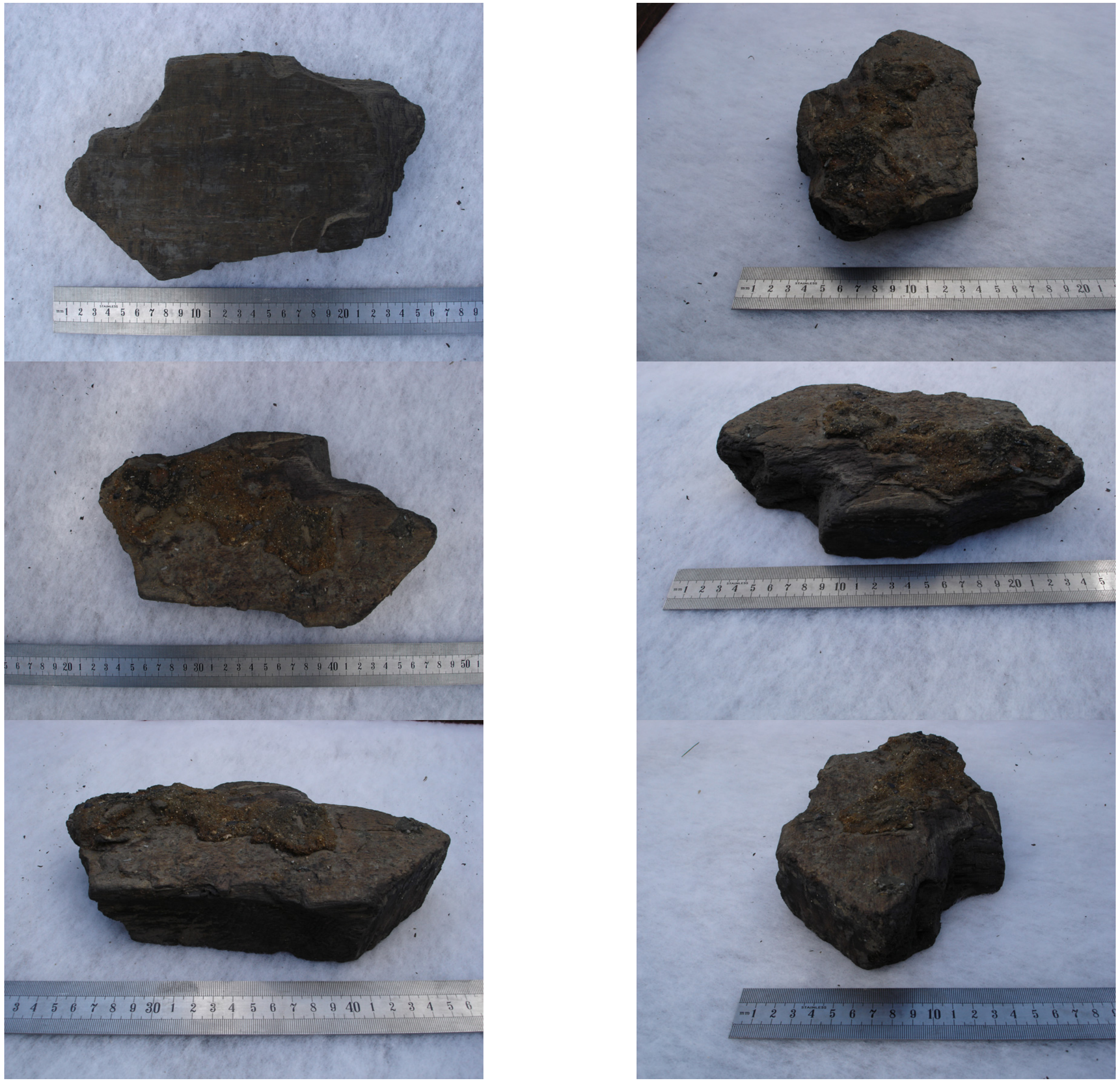


Figure 20: Beech plank from the well (**wt03**)

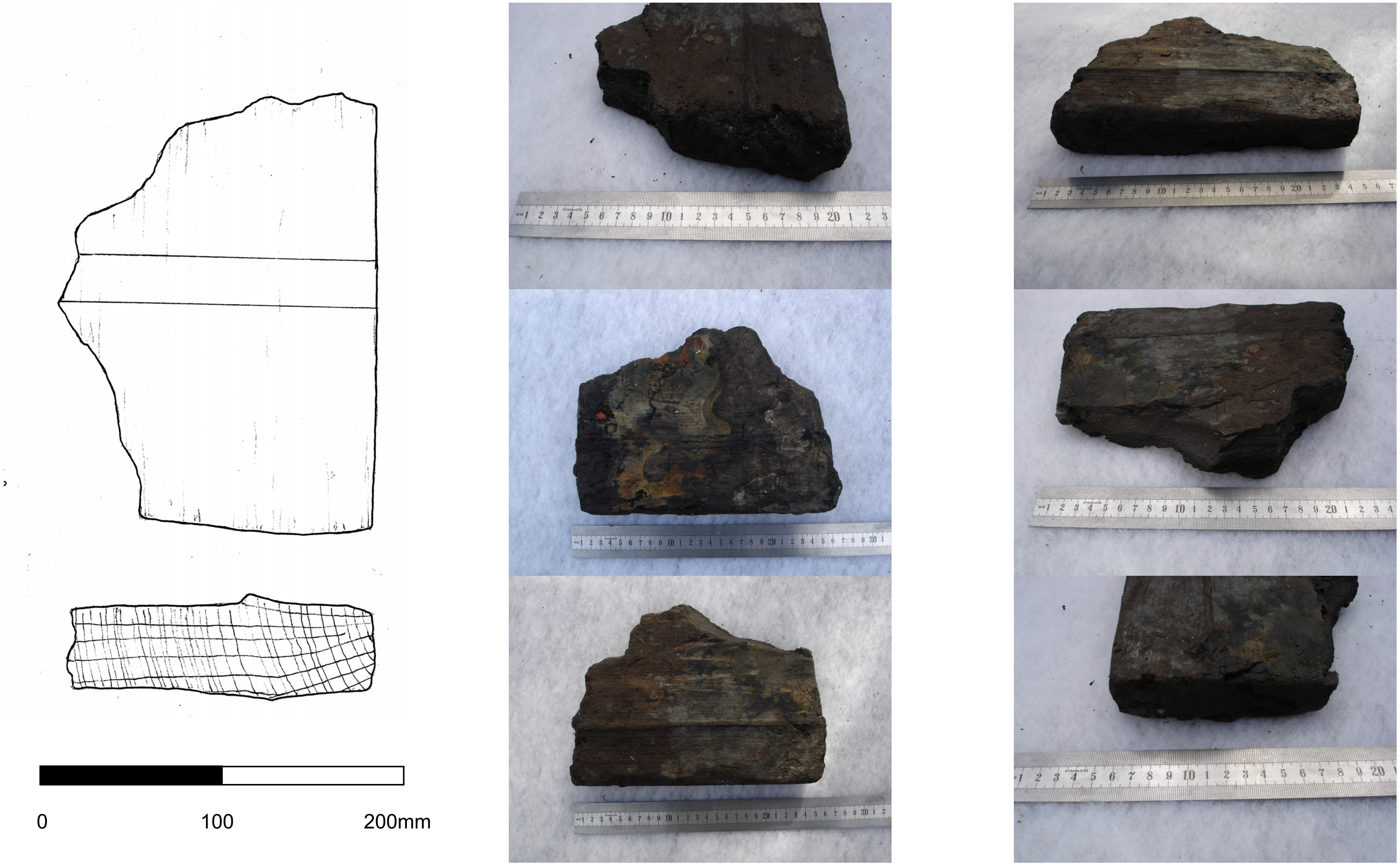
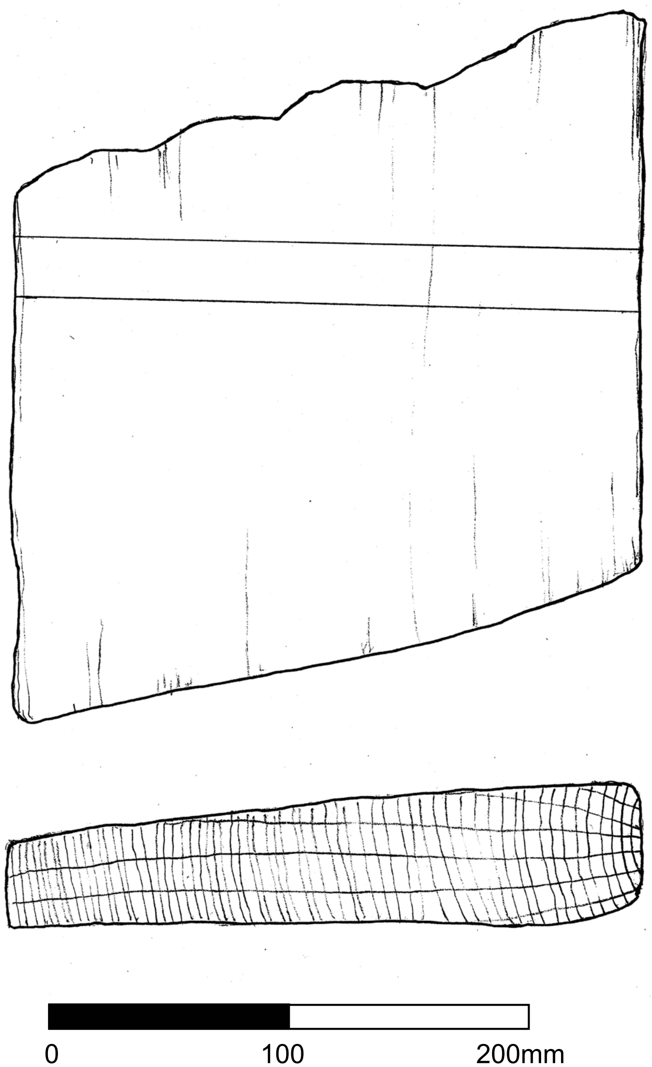


Figure 21: Beech plank from the well (**wt04**)



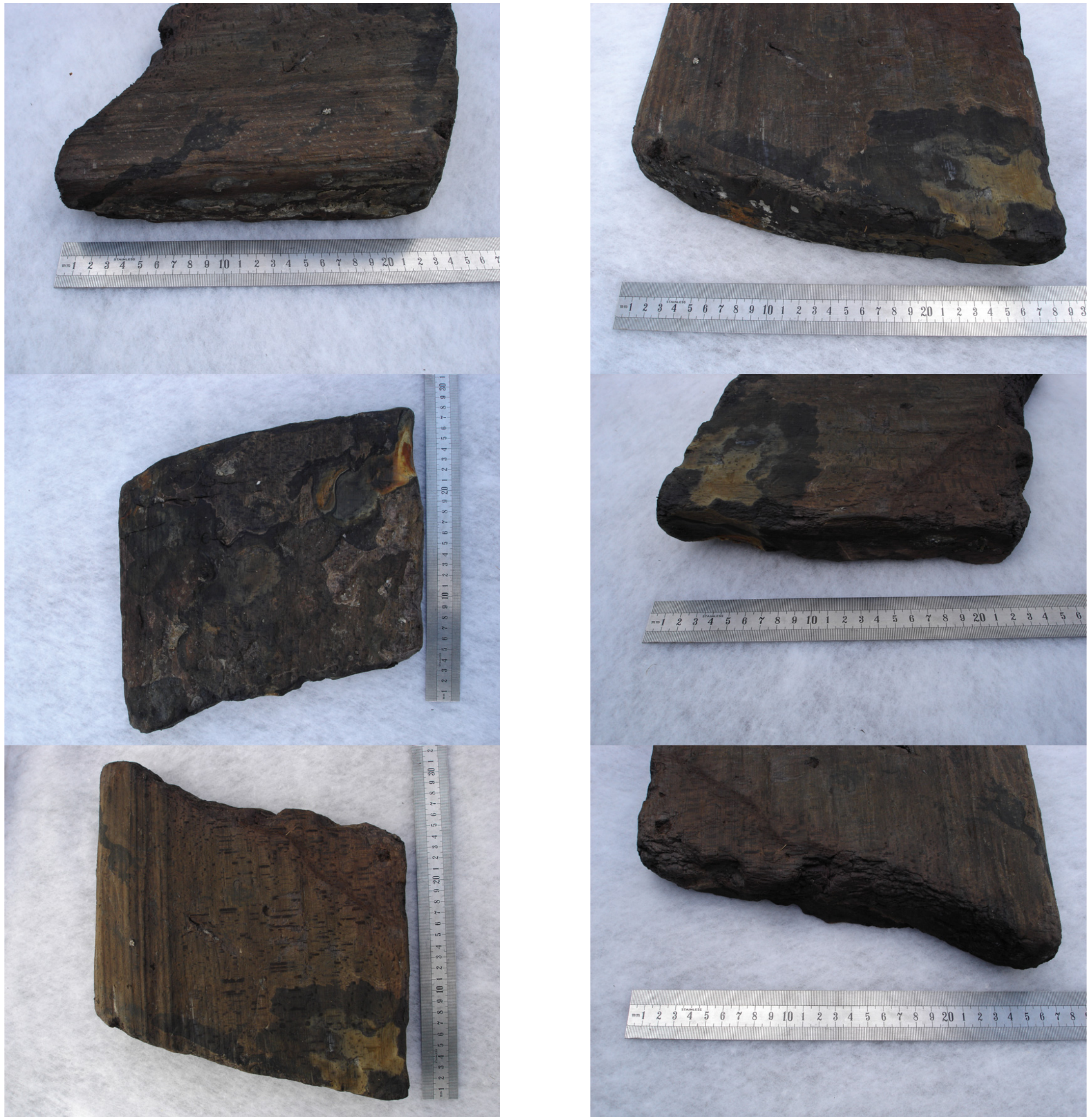


Figure 22: Beech plank from the well (**wt05**)

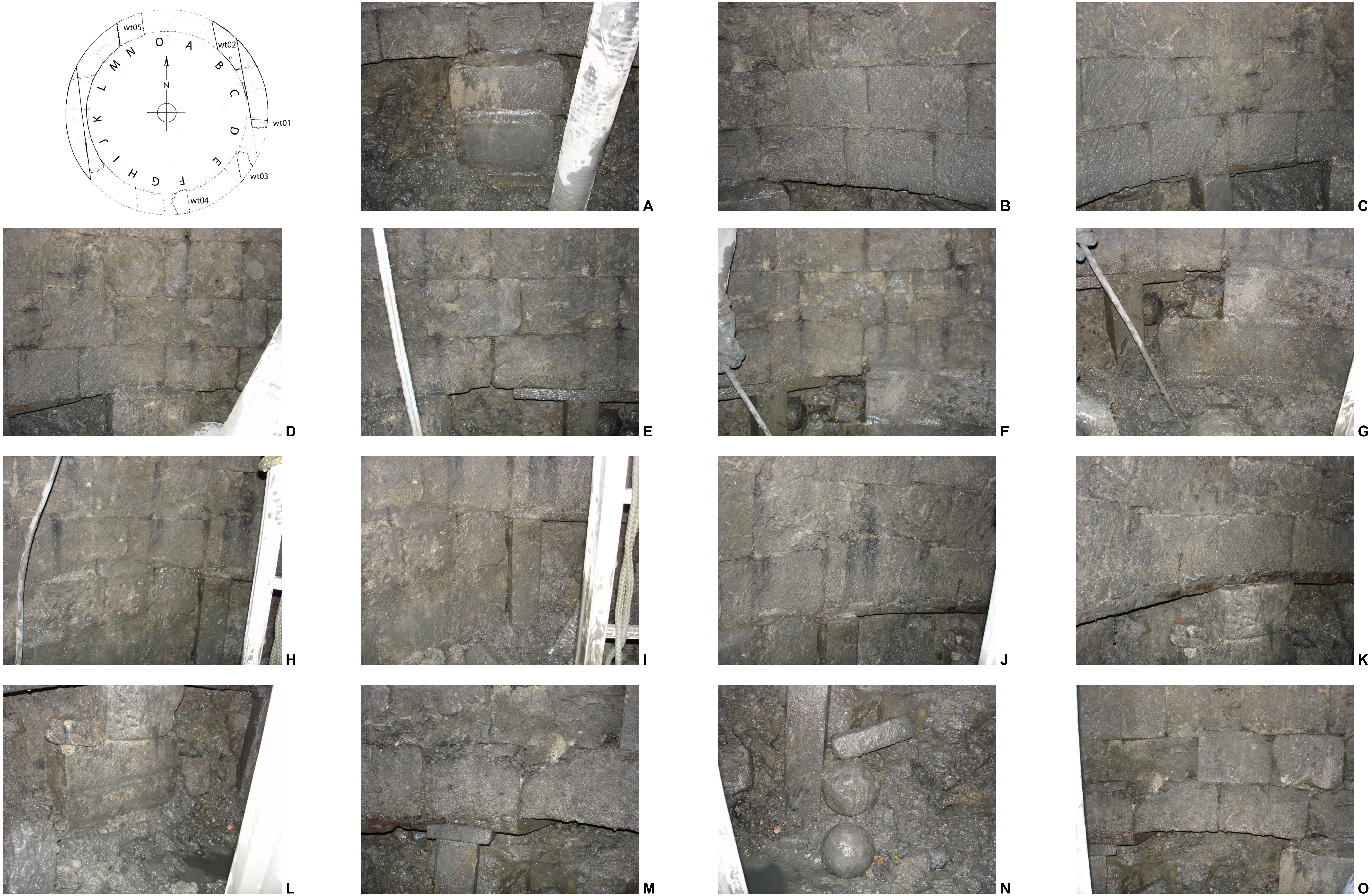


Figure 23: Photographs of bottom of well lining, showing later props

Figure 24: External door to south side of White Tower leading to chapel stair vice

Figure 25: Photograph of western room roof (copyright Historic Royal Palaces)

Junction of purlins and tiebeam

Junction of tiebeam and wallplates

Undersquinted abutment of firring pieces on tiebeam

Figure 26: Details of main roof construction

Figure 27: Southern tiebeam of western room roof showing blocked mortices

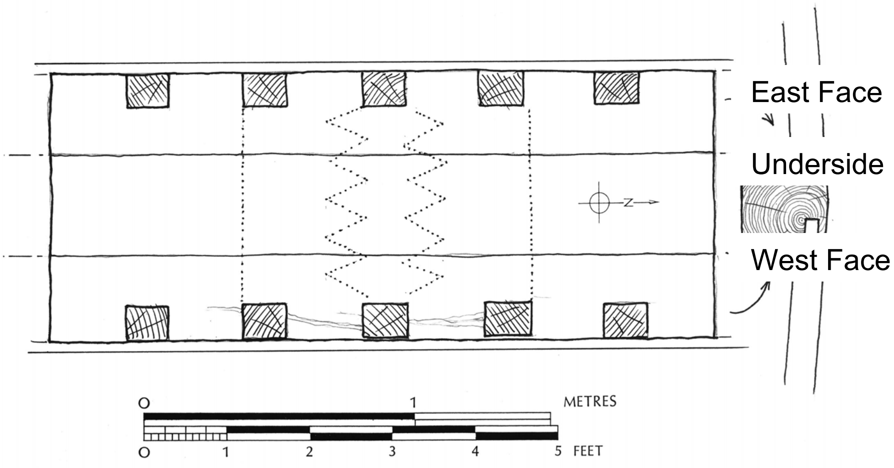


Figure 28: Southern ridge beam of western room showing decorative pattern of tacks

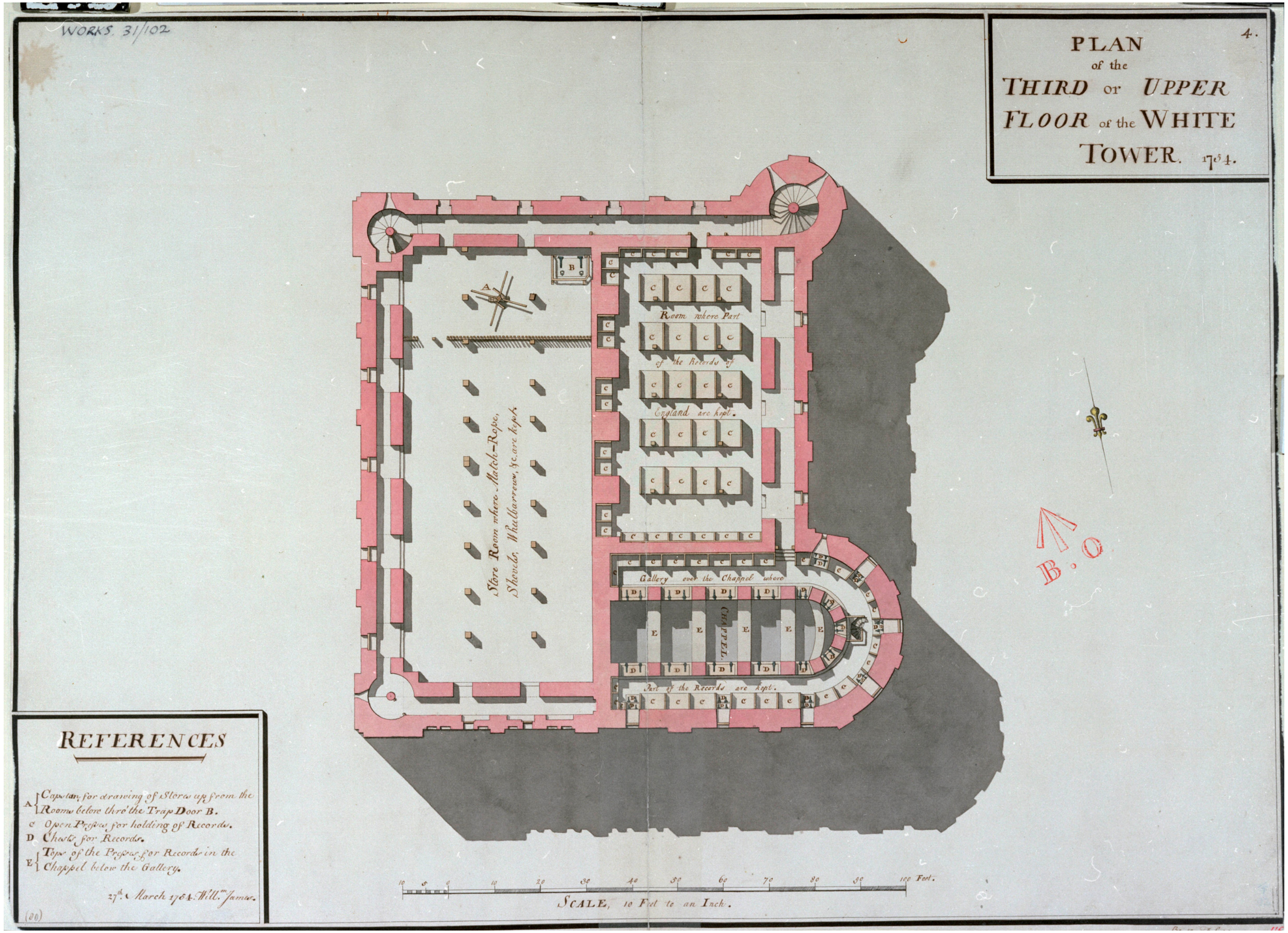


Figure 29: Second-floor plan by Lemprière in 1754 (TNA WORK31/102, copyright The National Archives)

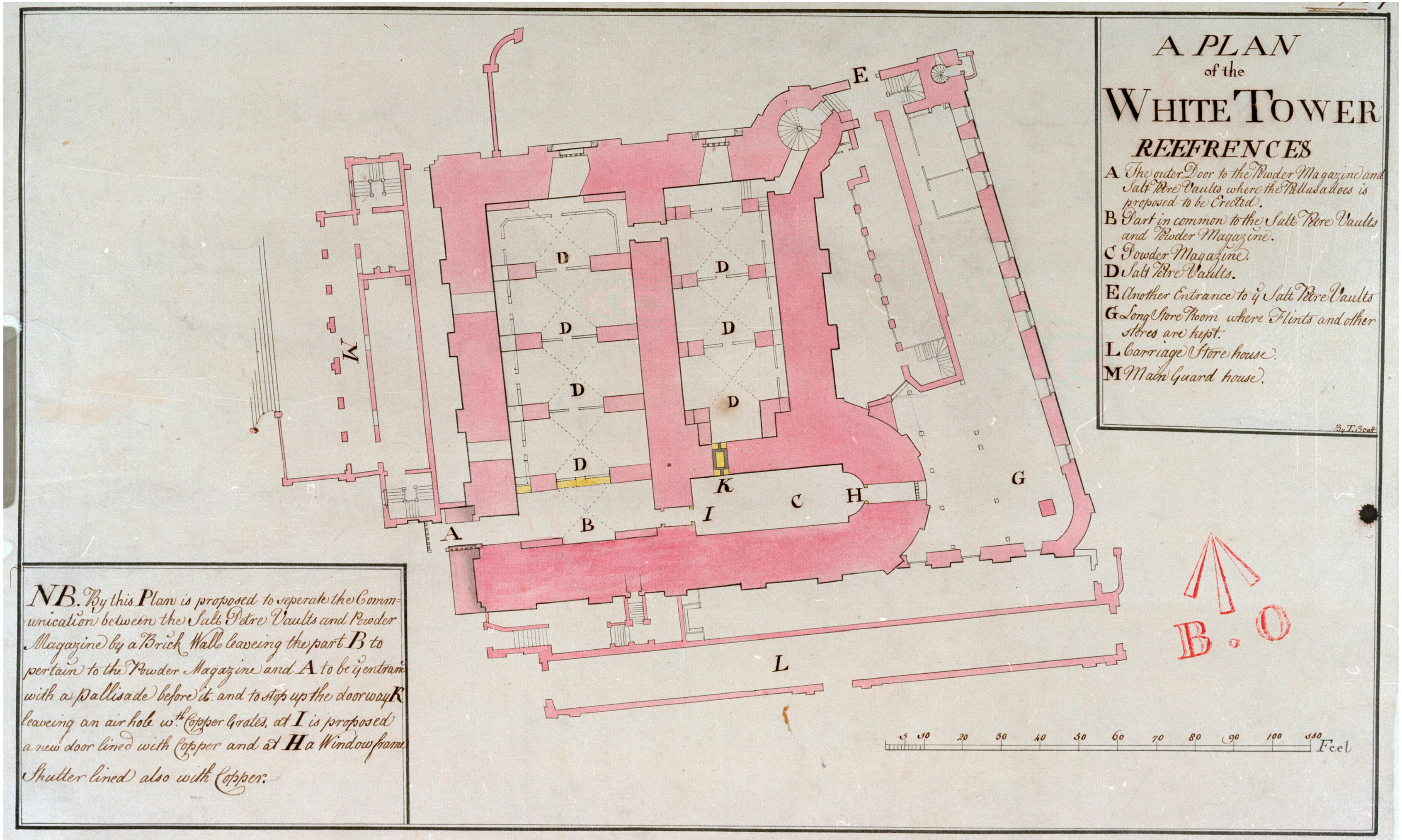


Figure 30: Basement plan by Lemprière in 1754 (TNA WORK31/104, copyright The National Archives)

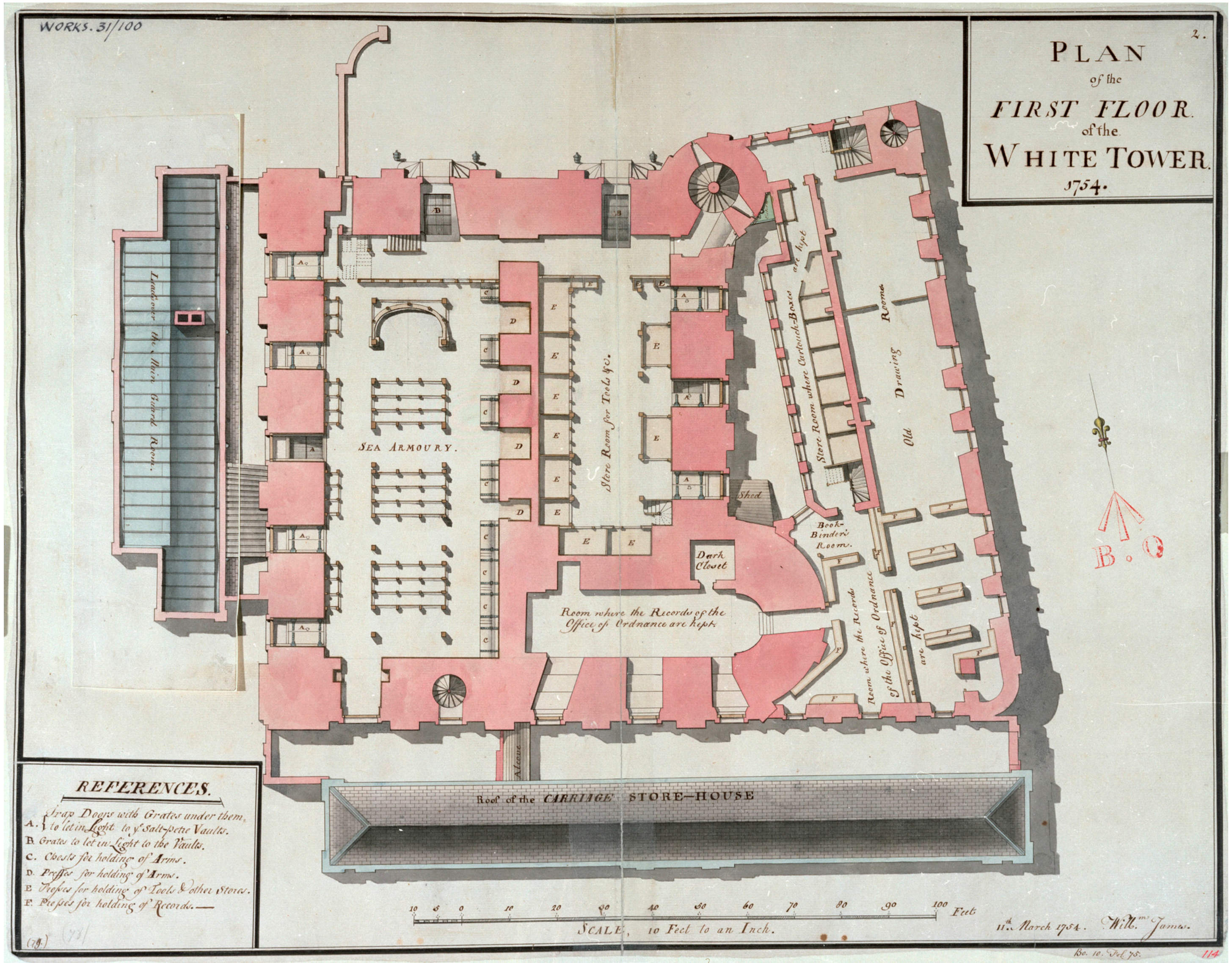


Figure 31: Ground-floor plan by Lemprière in 1754 (TNA WORK31/100, copyright The National Archives)

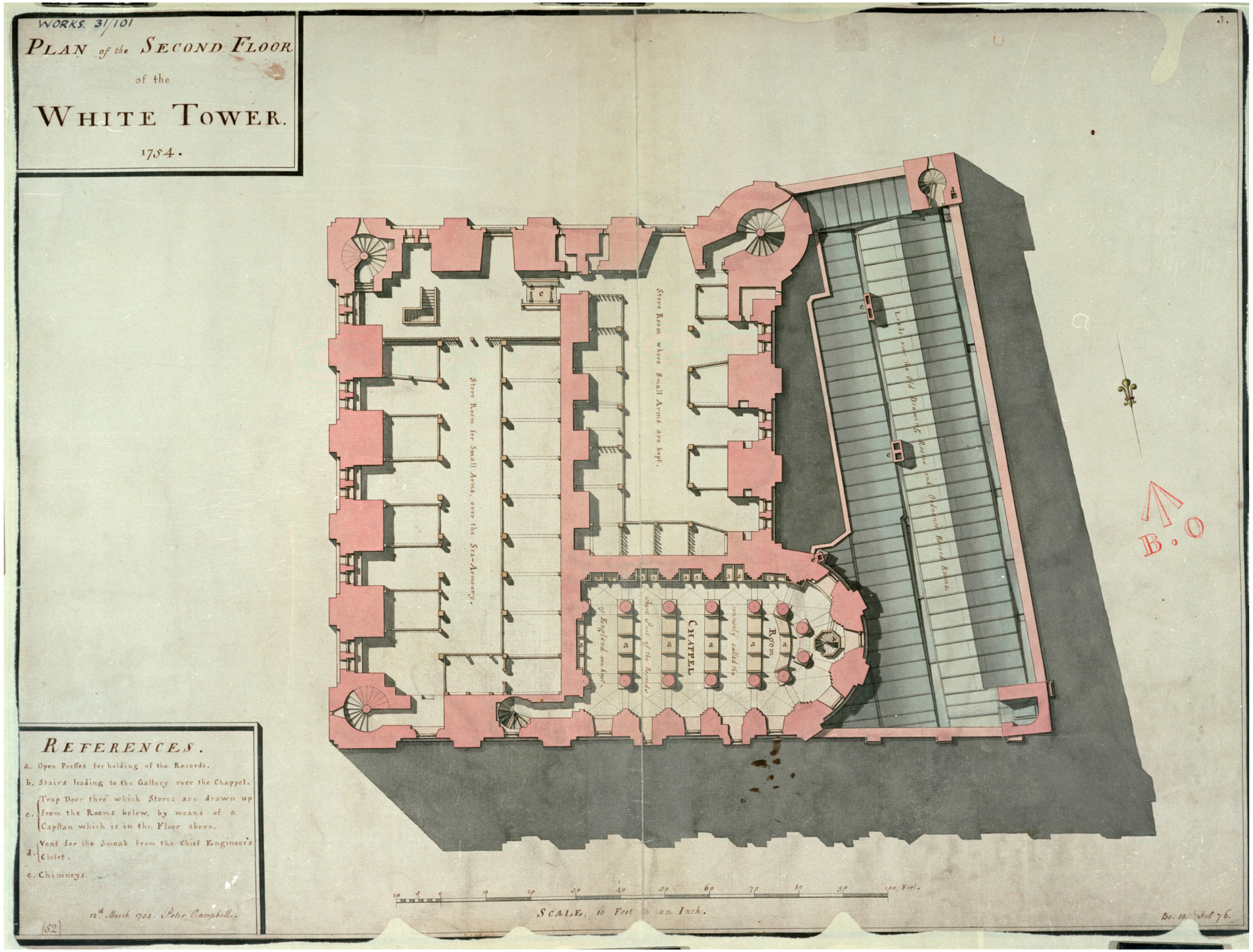


Figure 32: First-floor plan by Lemprière in 1754 (TNA WORK31/101, copyright The National Archives)

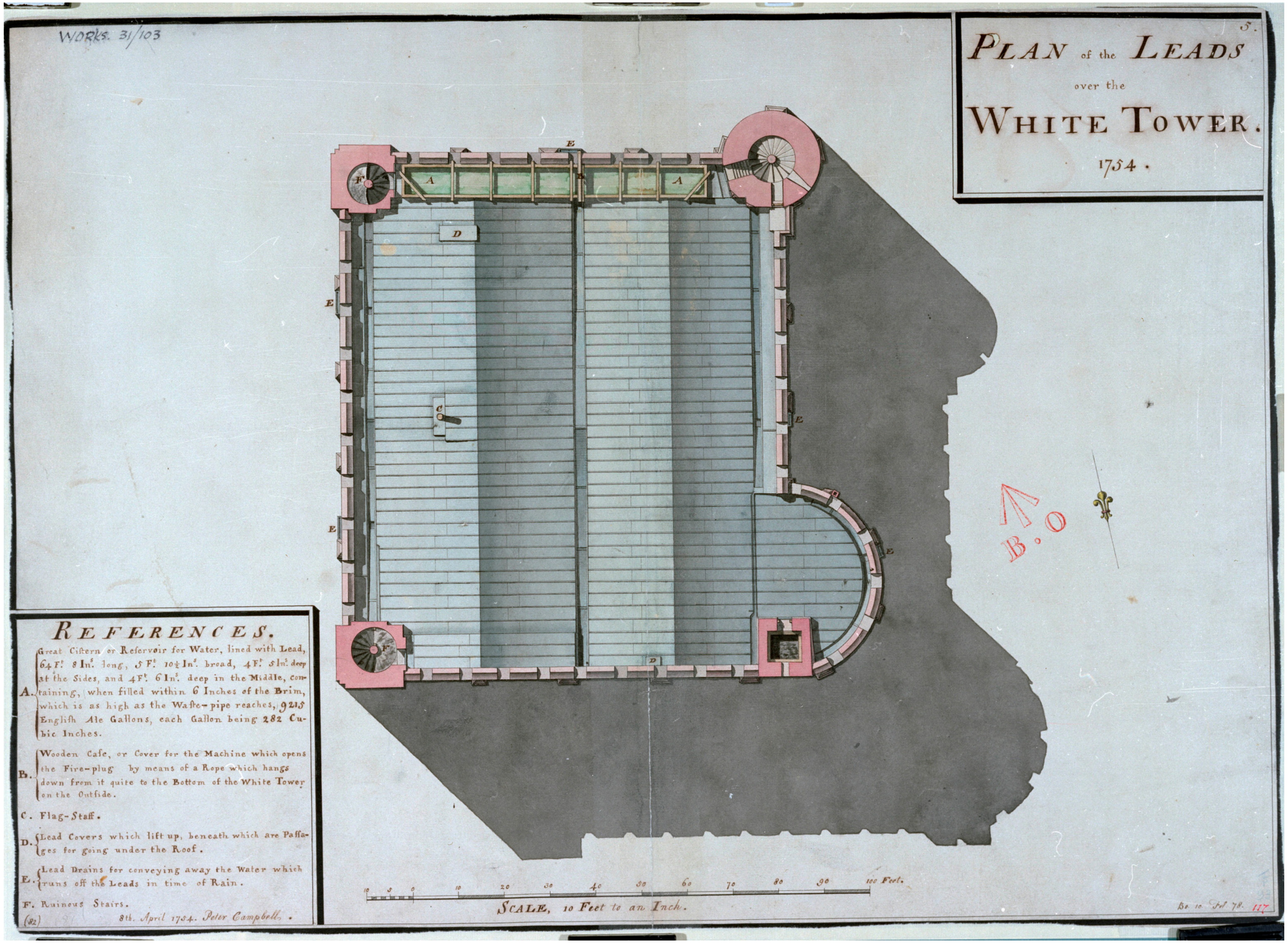


Figure 33: Roof plan by Lemprière in 1754 (TNA WORK31/103, copyright The National Archives)

Figure 34: View of Flamsteed Turret

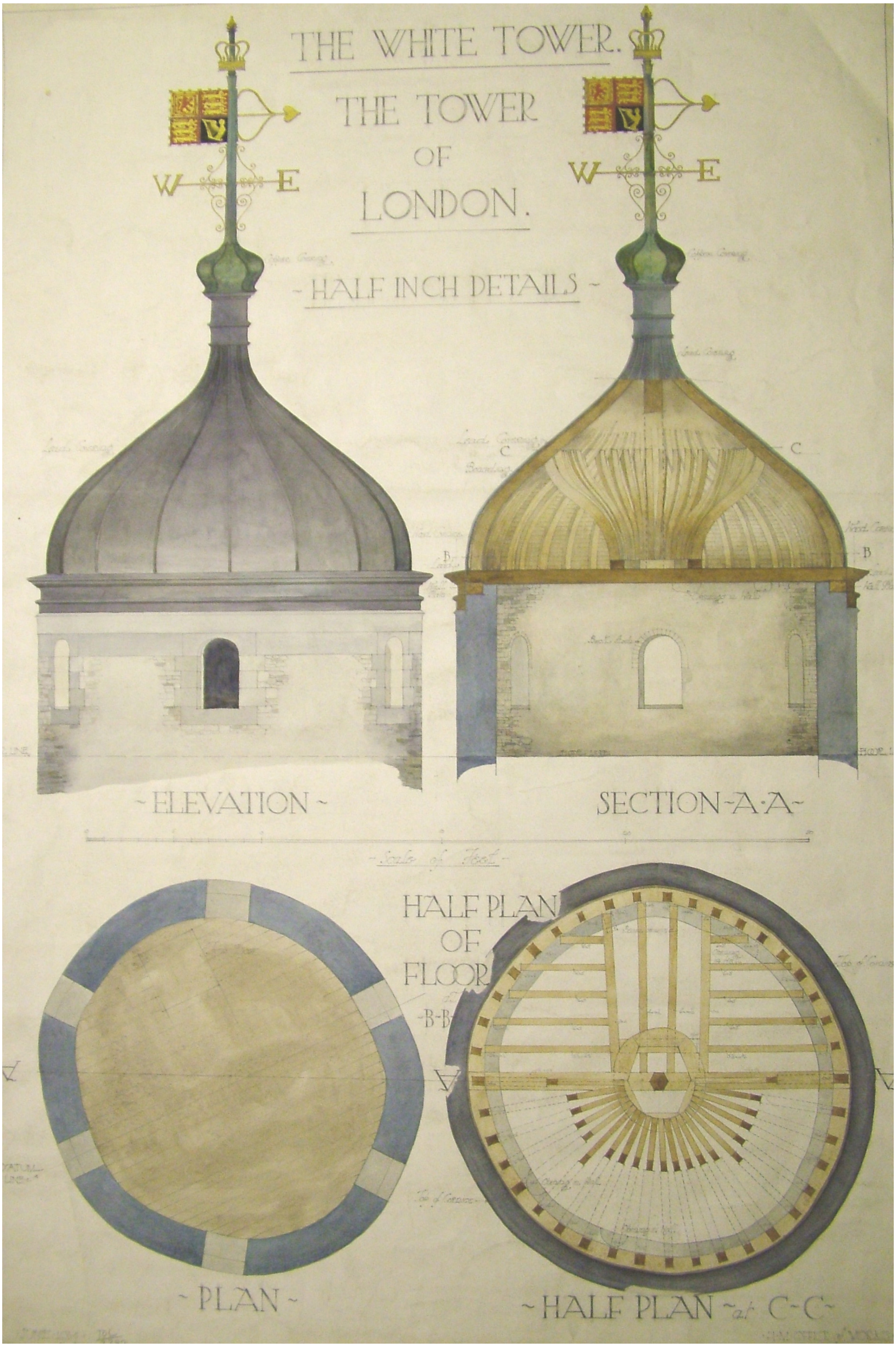


Figure 35: Plans and sections of the Flamsteed Turret, Ministry of Works 1914 (HRP TOL 2382, copyright Historic Royal Palaces)

Figure 36: View of north-west turret

Figure 37: Upper floor, north-west turret

Figure 38: Roof, north-west turret

Figure 39: View of south-east turret

Figure 40: Beam and joist comprising lower floor of south-east turret

Figure 41: Second-floor details of south-east turret

Figure 42: Underside of roof of south-east turret

Figure 43: View of south-west turret

Figure 44: Second-floor details and cross-braces in south-west turret

Figure 45: View of roof inside south-west turret

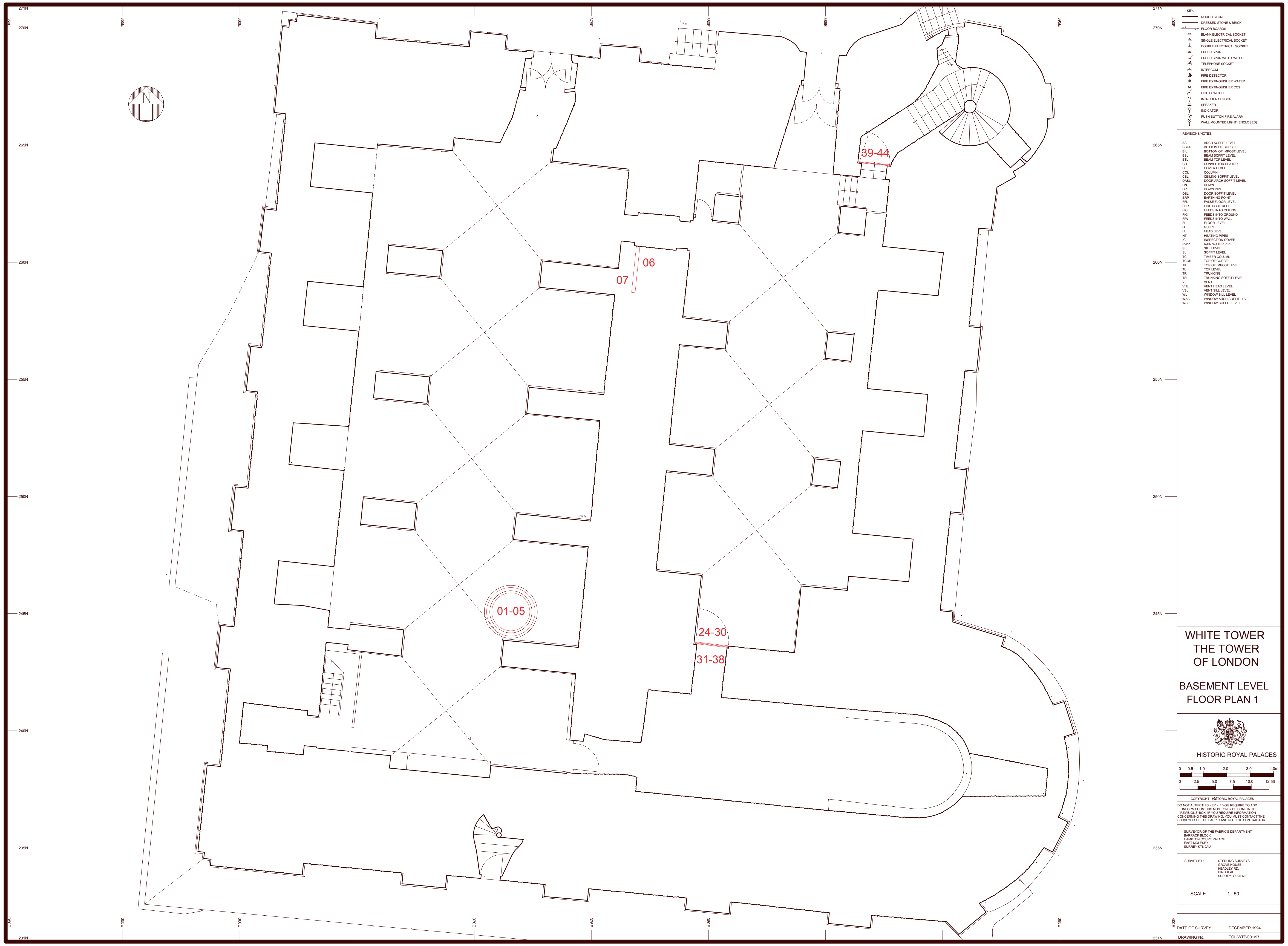


Figure 46: Plan of basement level showing locations of timbers sampled (after Historic Royal Palaces)

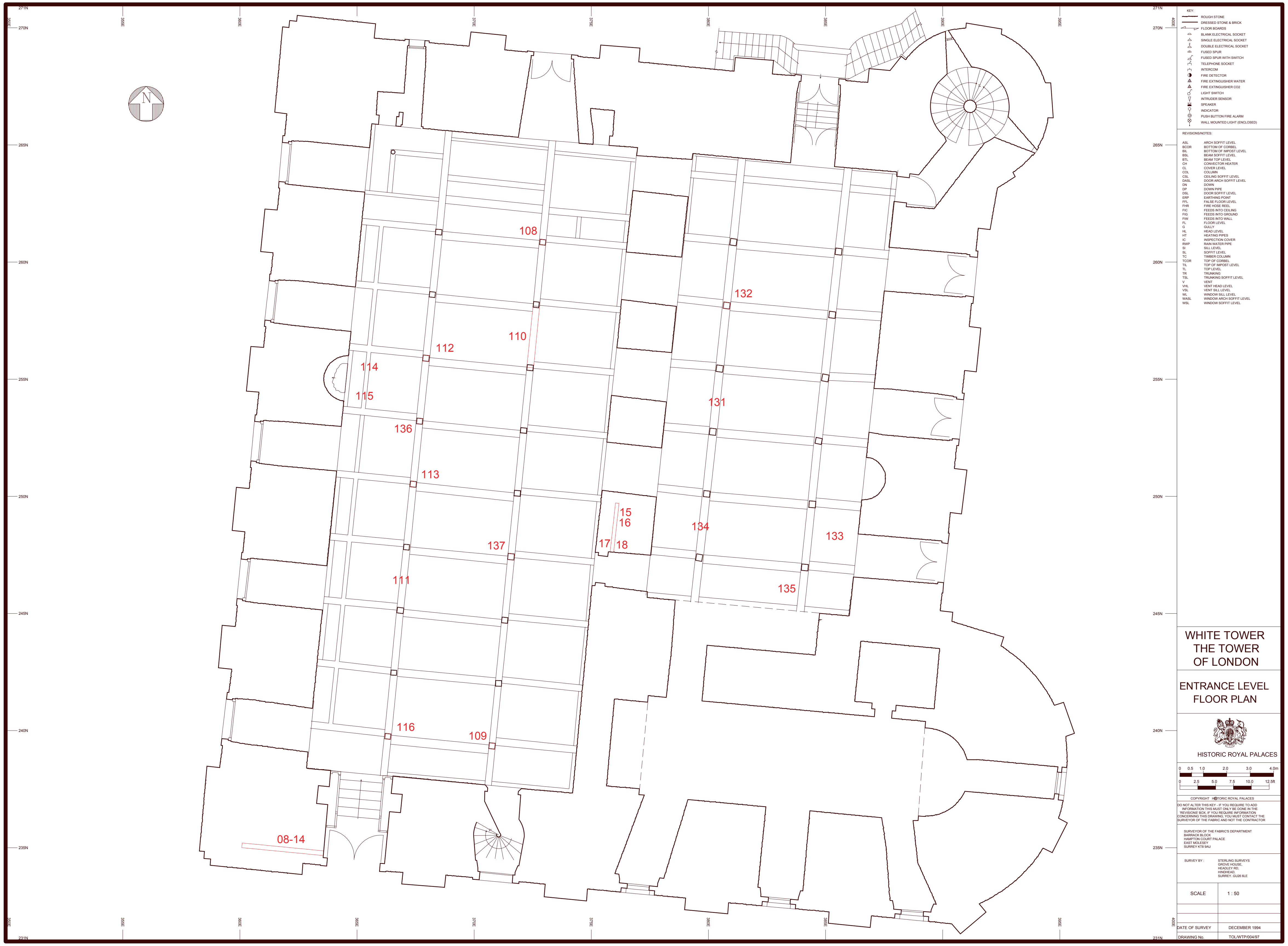


Figure 47: Plan of entrance (ground-floor) level showing locations of timbers sampled (after Historic Royal Palaces)

Figure 48: Plan of first-floor level showing locations of timbers sampled (after Historic Royal Palaces)

Figure 49: Plan of second-floor level showing locations of timbers sampled (after Historic Royal Palaces)

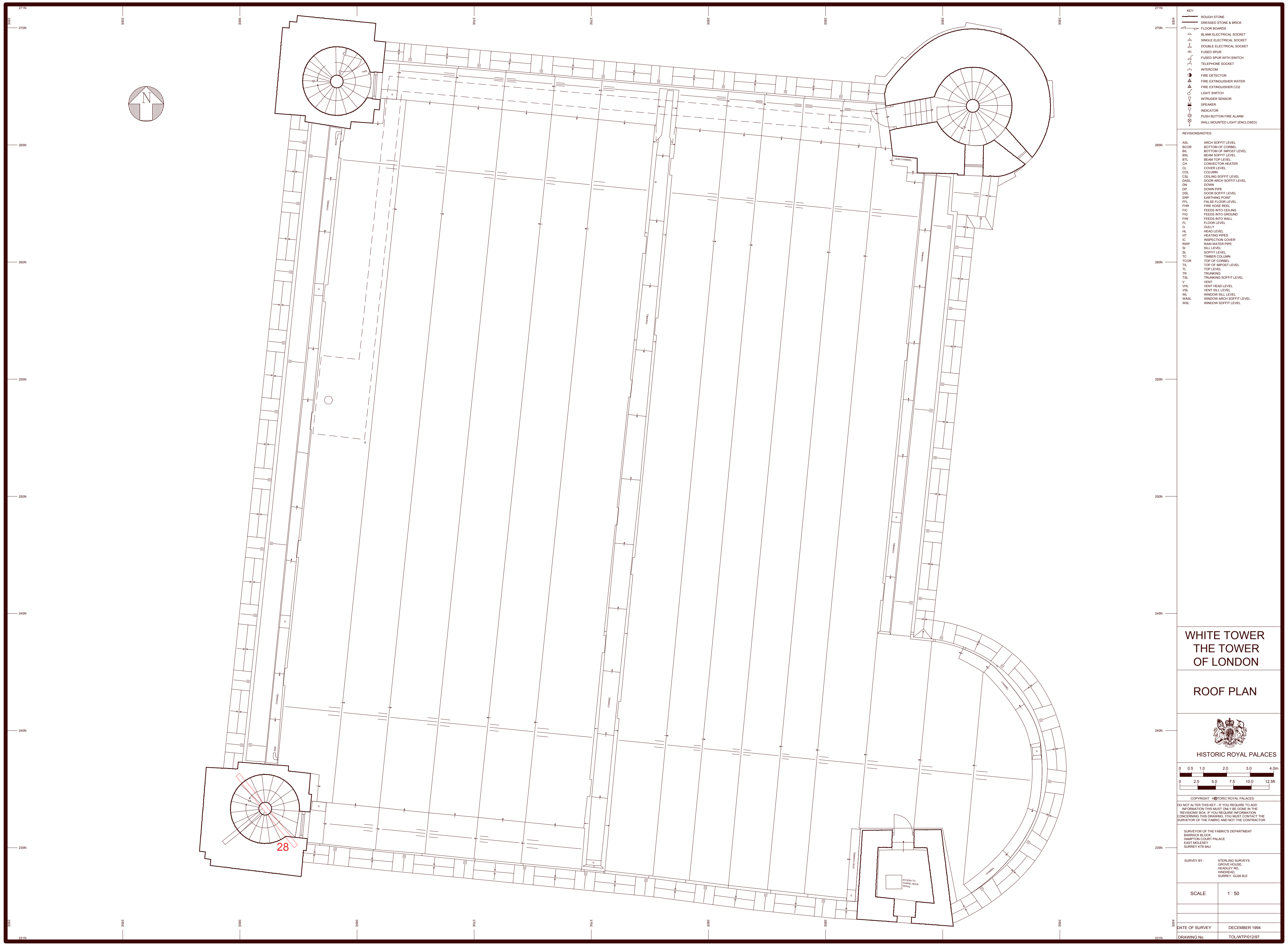


Figure 50: Plan of roof level showing locations of timbers sampled (after Historic Royal Palaces)

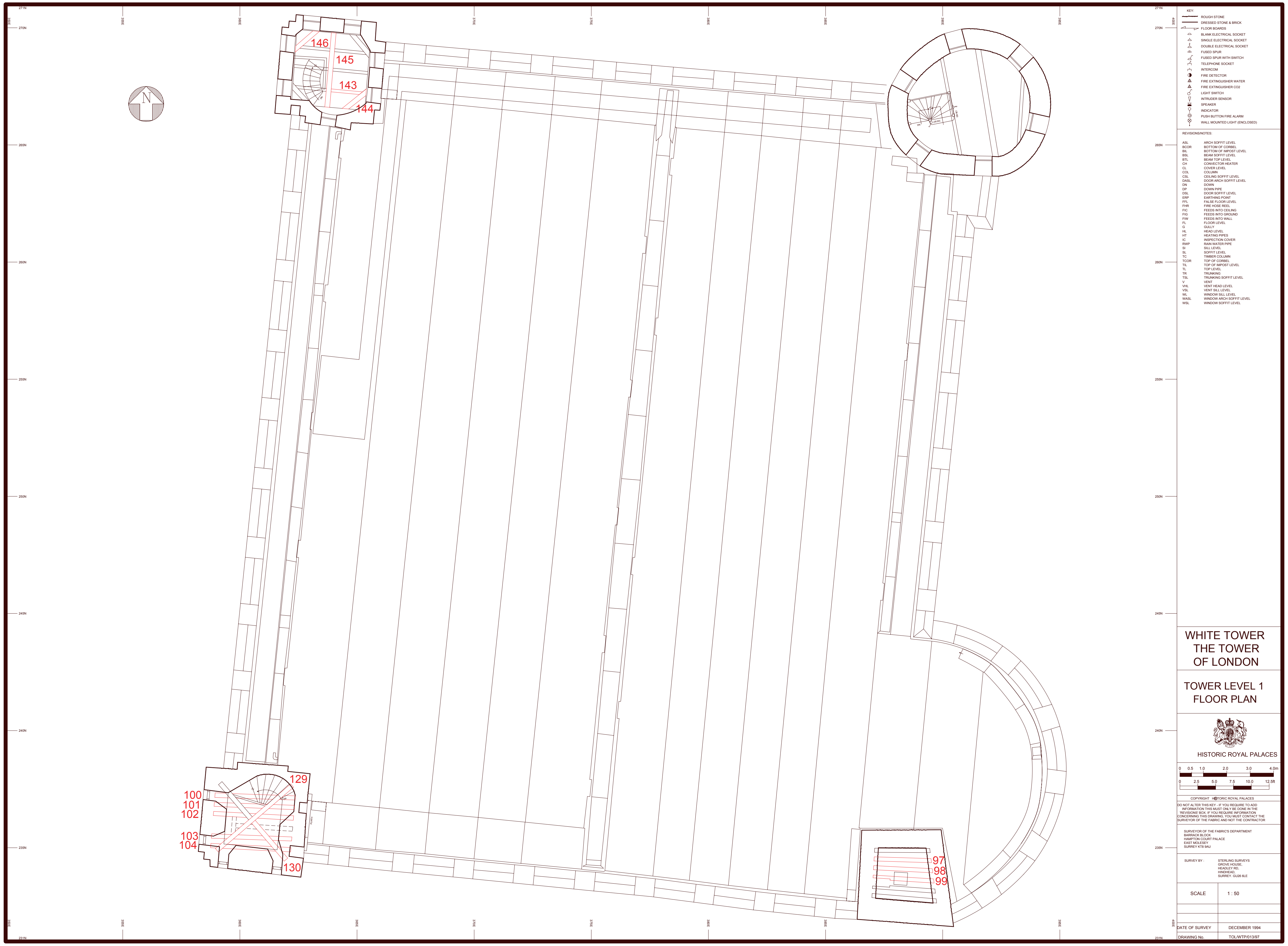


Figure 51: Plan of first-floor level of turrets showing locations of timbers sampled (after Historic Royal Palaces)

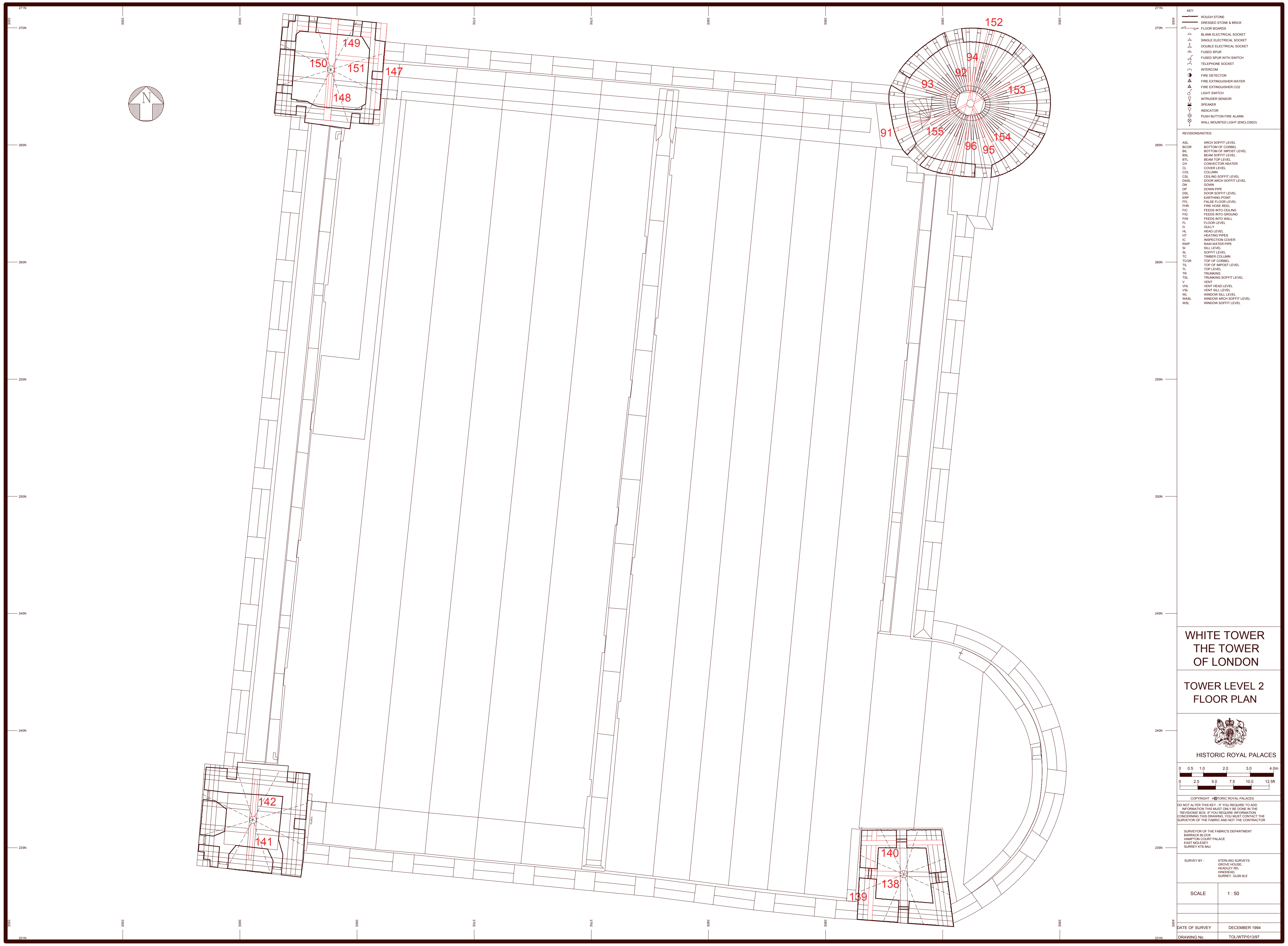


Figure 52: Plan of second-floor level of turrets showing locations of timbers sampled with roof structure overlaid (after Historic Royal Palaces)

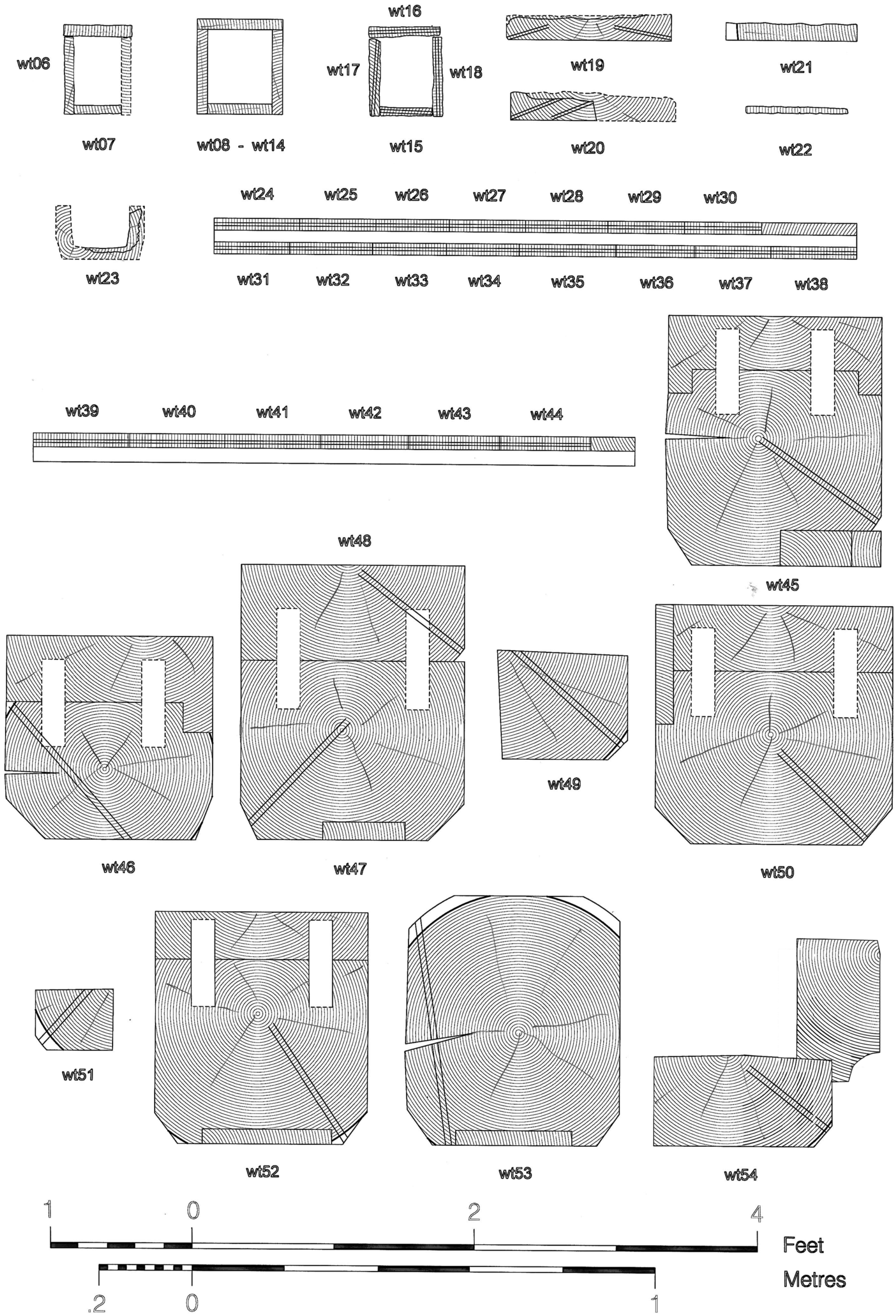


Figure 53: Section drawings of timbers sampled

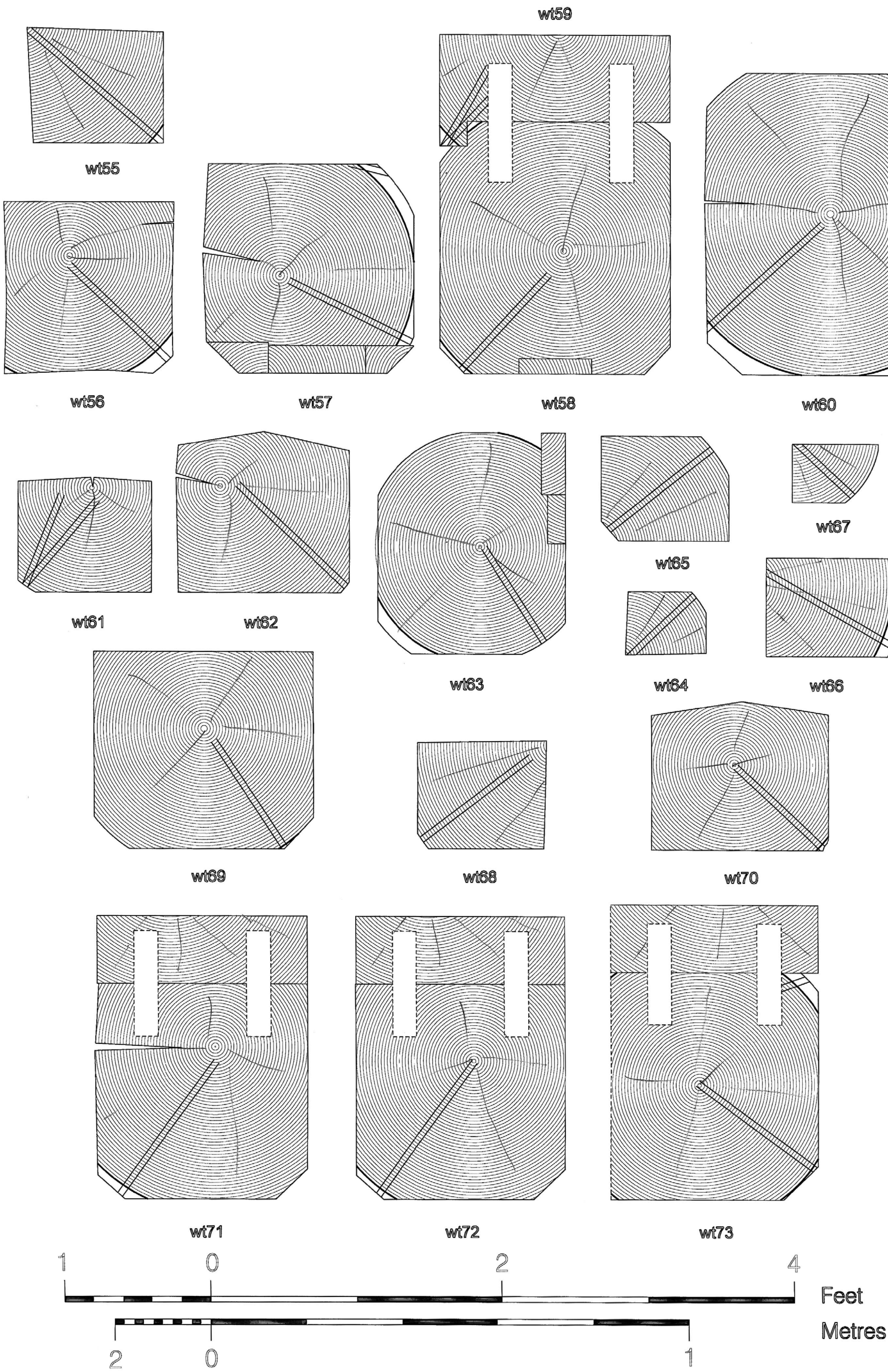


Figure 53: Section drawings of timbers sampled (continued)

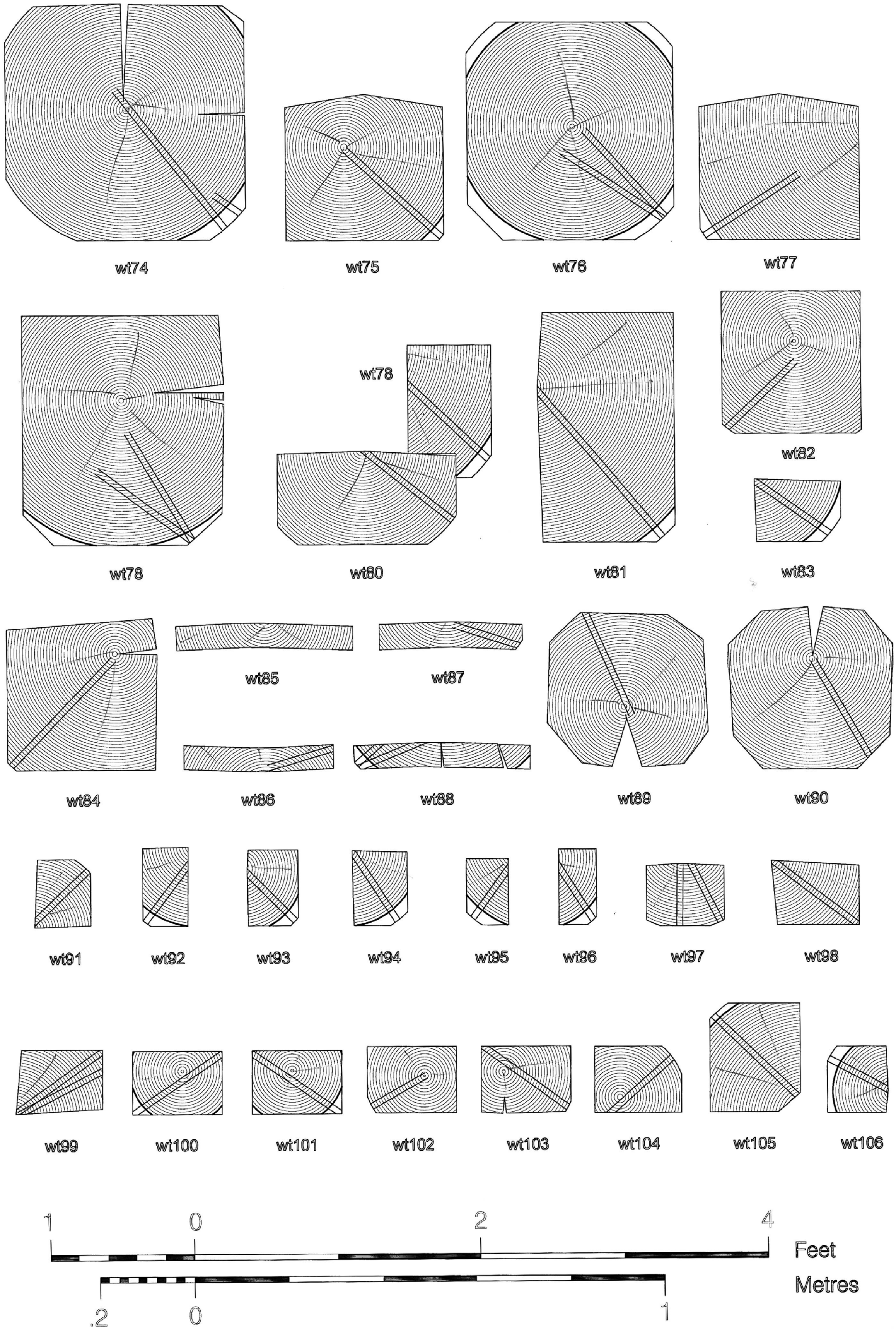


Figure 53: Section drawings of timbers sampled (continued)

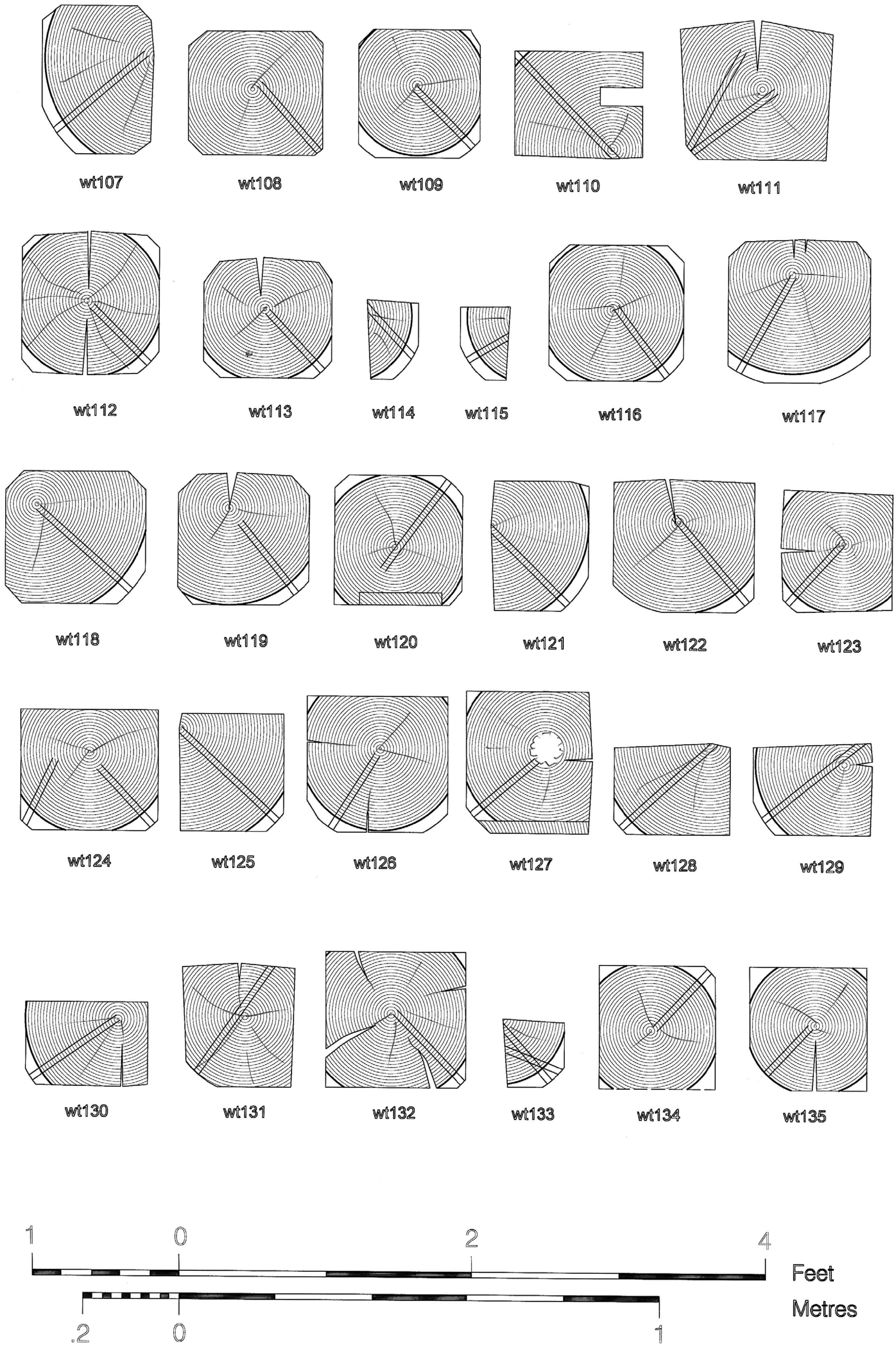


Figure 53: Section drawings of timbers sampled (continued)

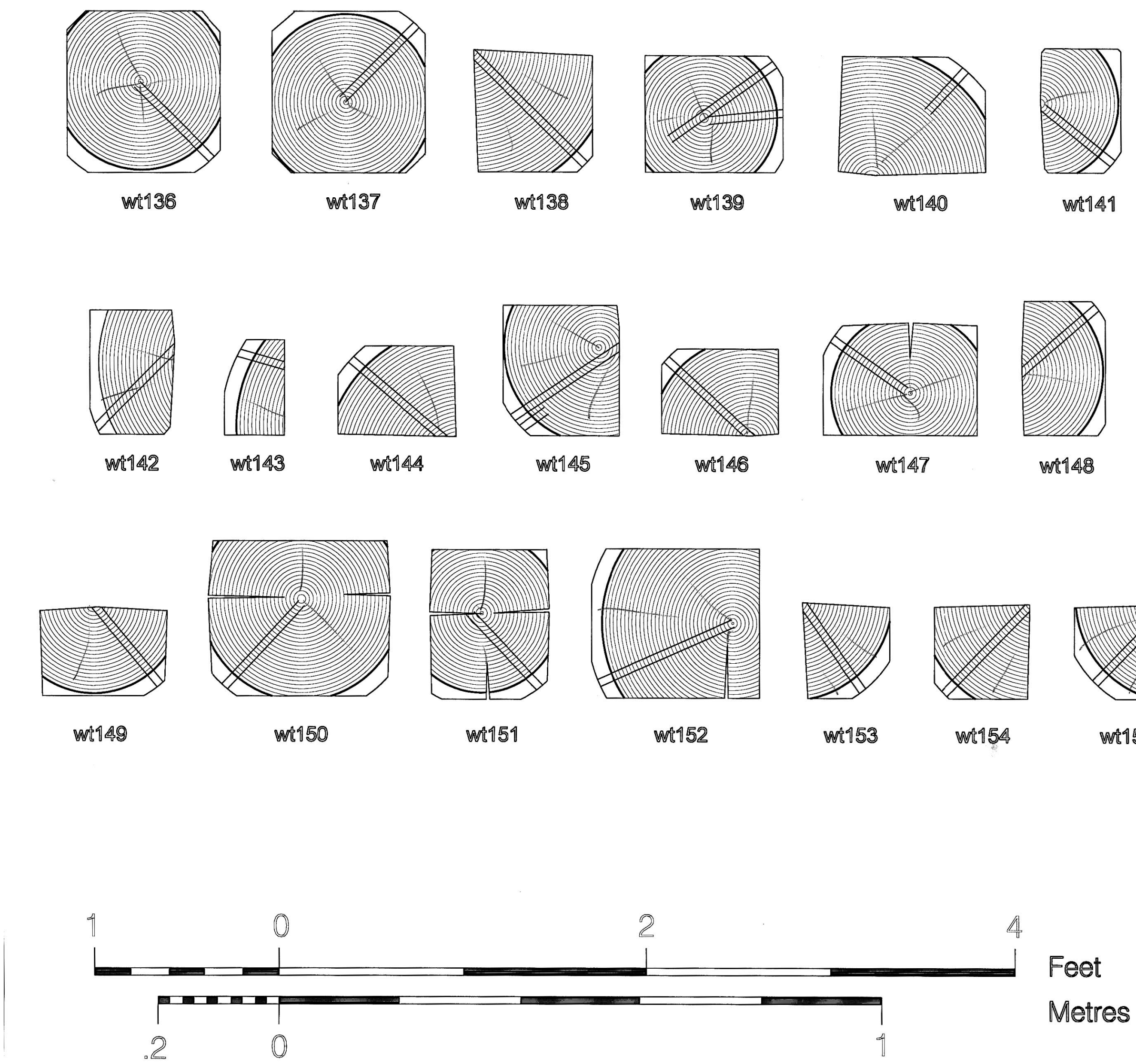


Figure 53: Section drawings of timbers sampled (continued)

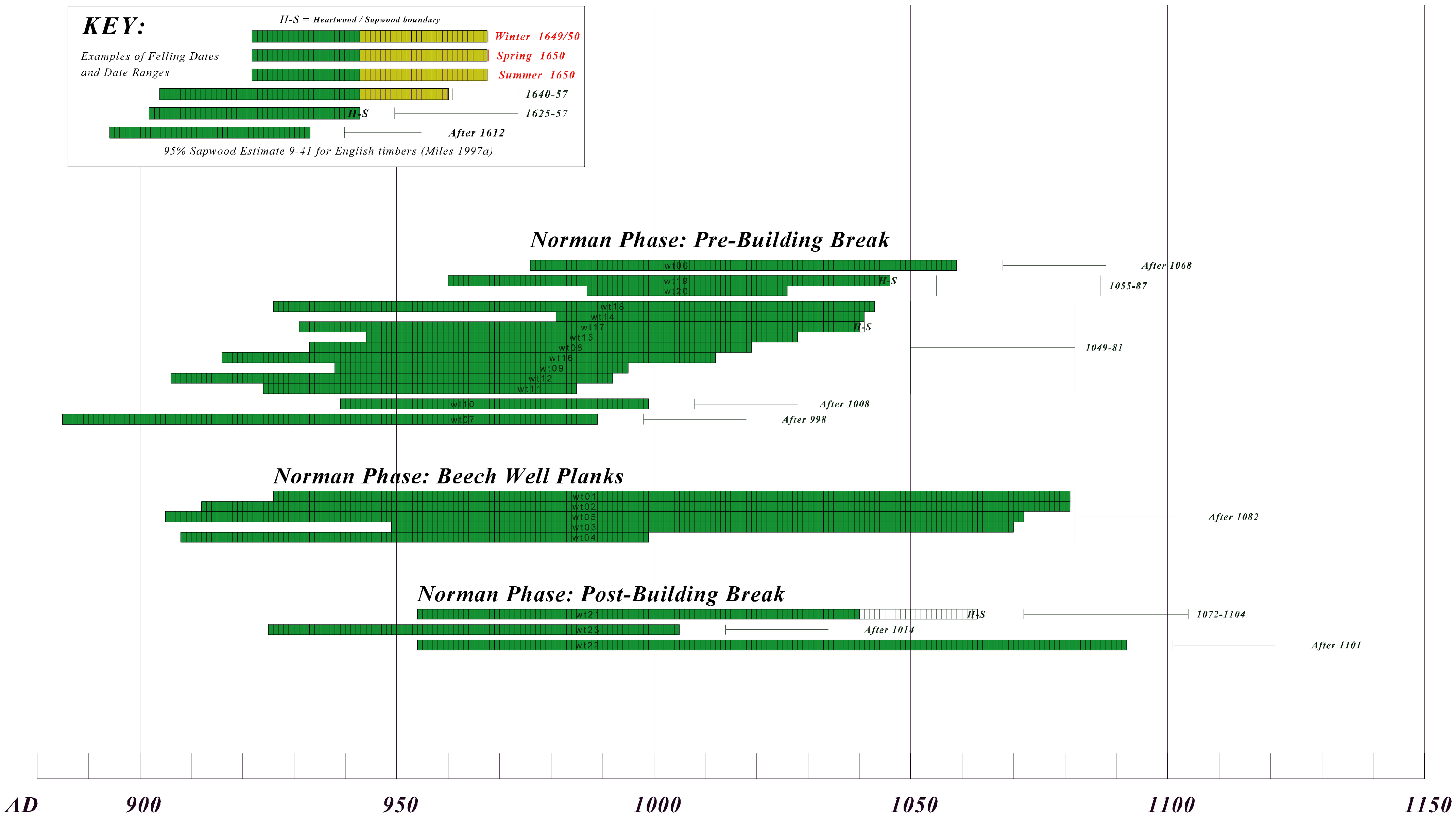


Figure 54: Bar diagram showing dated Norman-phase samples in chronological position

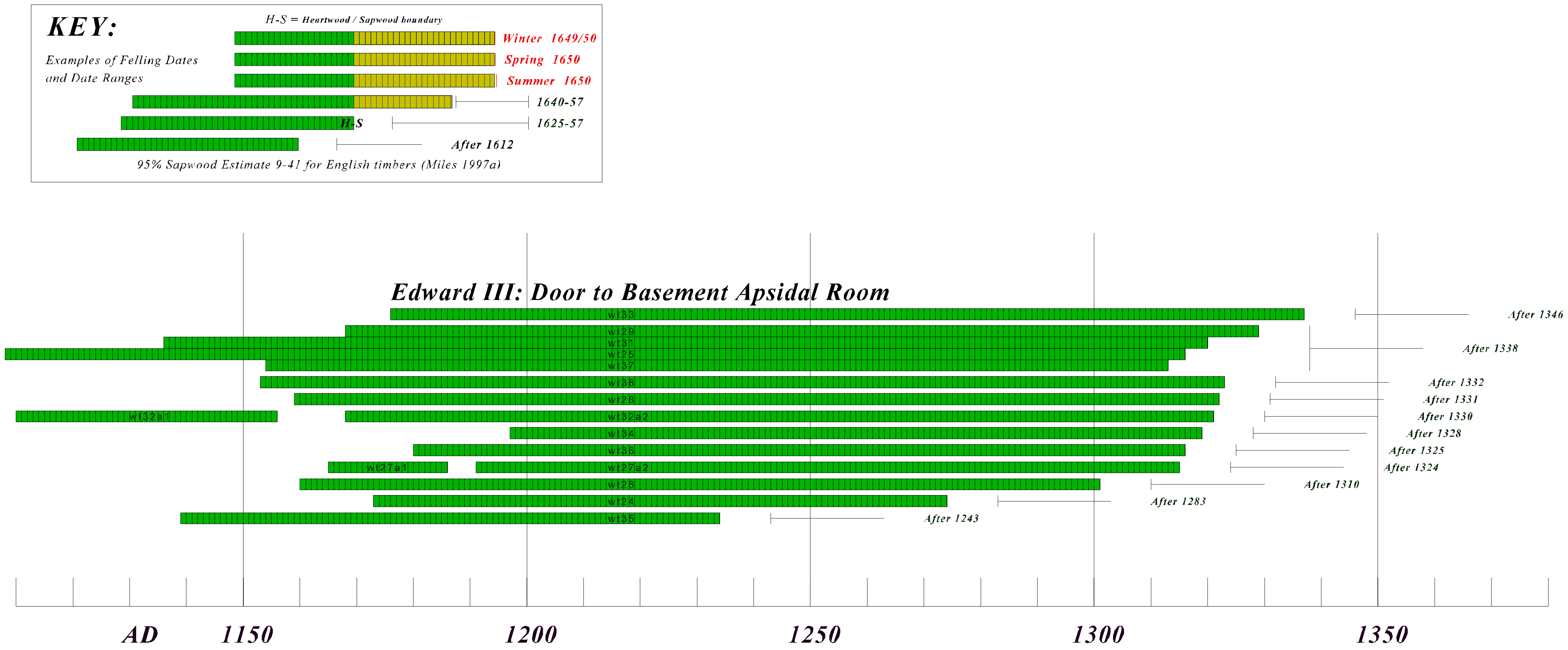


Figure 55: Bar diagram showing dated fourteenth-century samples in chronological position

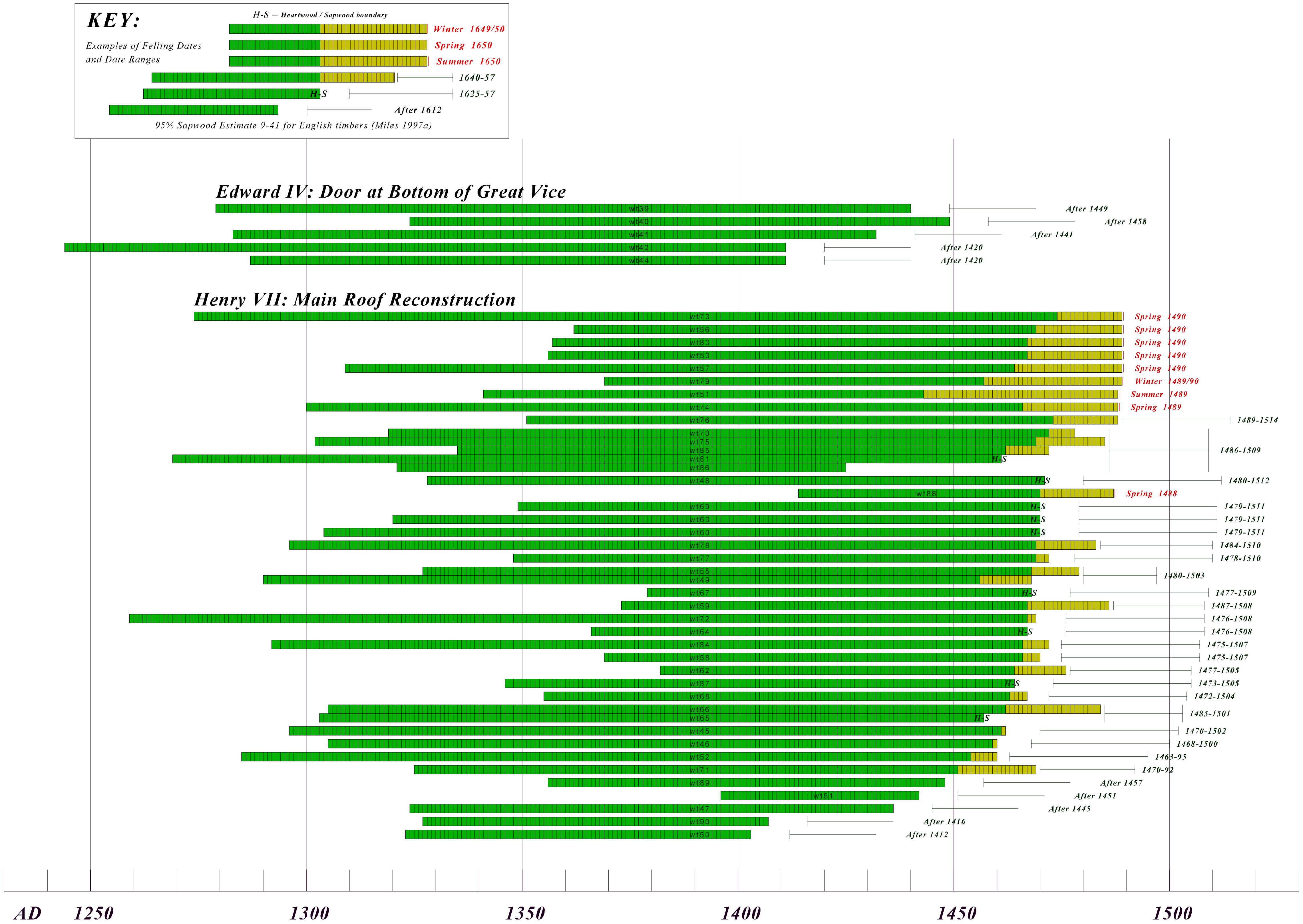


Figure 56: Bar diagram showing dated fifteenth-century samples in chronological position

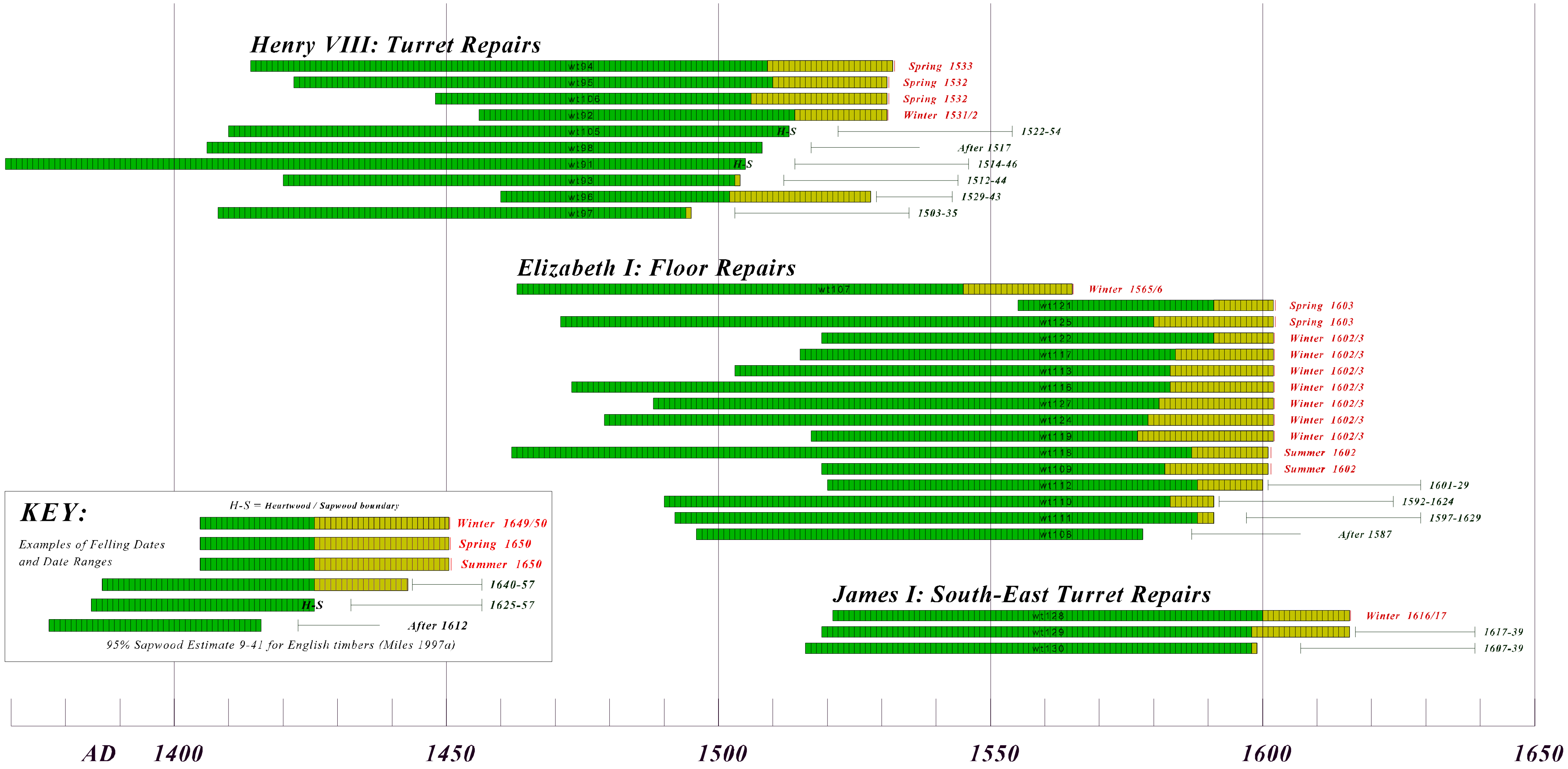


Figure 57: Bar diagram showing dated sixteenth- and seventeenth-century samples in chronological position

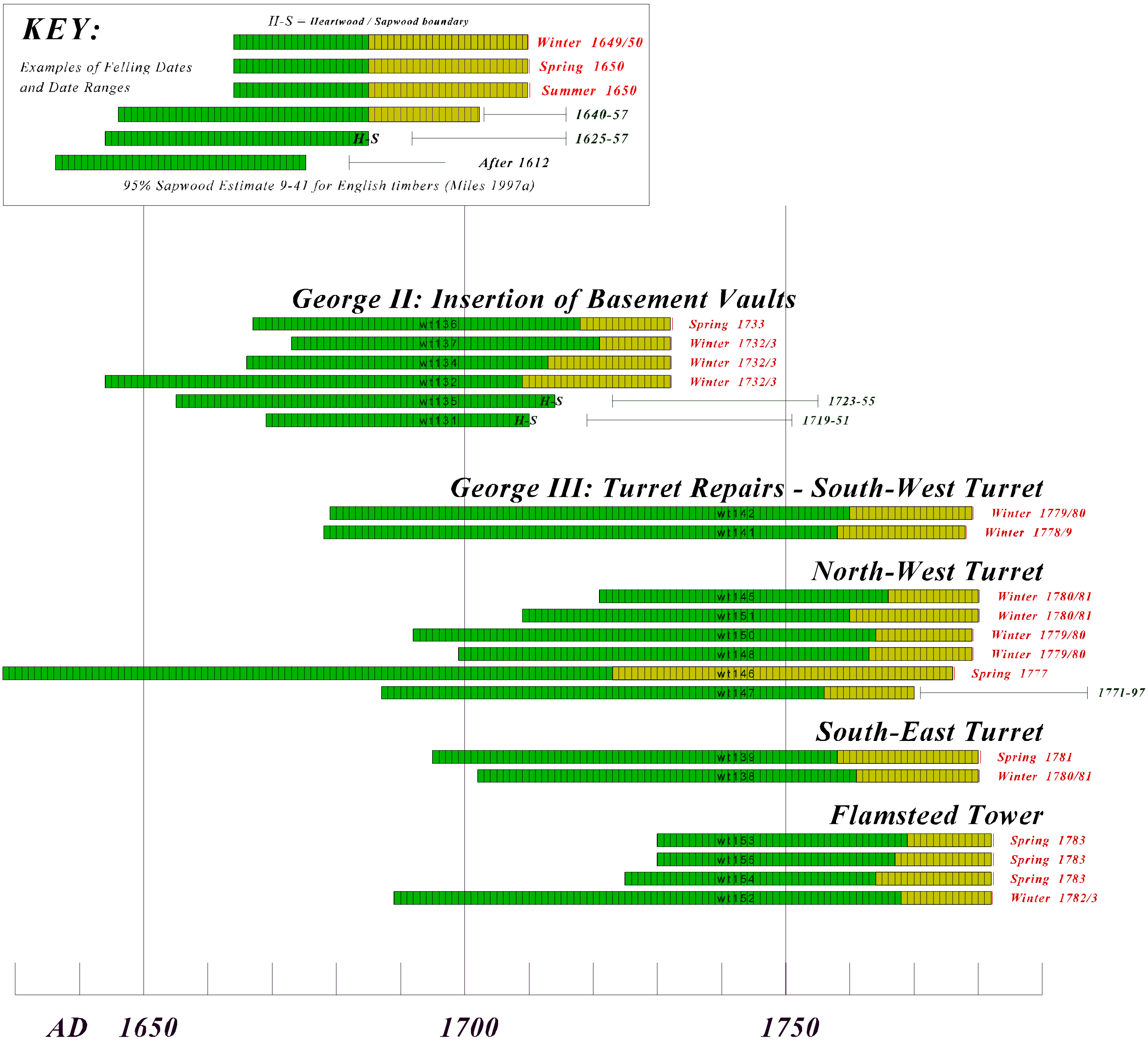


Figure 58: Bar diagram showing dated eighteenth-century samples in chronological position