HISTORIC BUILDING RECORDING AND WATCHING BRIEF ON THE REPAIR (PHASE II) OF THE FLAMSTEED TURRET STEPS IN THE WHITE TOWER, HM TOWER OF LONDON, LONDON BOROUGH OF TOWER HAMLETS

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PRE-CONSTRUCT ARCHAEOLOGY

Historic Building Recording and Watching Brief on the repair (Phase II) of the Flamsteed Turret Steps in the White Tower, HM Tower of London, London Borough of Tower Hamlets

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1 NON-TECHNICAL SUMMARY

1.1.1 Pre-Construct Archaeology Limited was commissioned by Historic Royal Palaces to undertake building recording in connection with the replacement of the protective timber staircase in the Flamsteed Turret at the Tower of London. This turret is one of the four turrets at the corners of the White Tower and is centred on OS NGR TQ 33633 80568. An Historic England Level 2 survey of the timber covers and a Level 3 record and petrological assessment of the underlying stone stair vice built from 1075/79 to 1100 was undertaken.

1.1.2 The petrological analysis of the steps identified the same 1080 to 1090/93 building break as that seen elsewhere in the fabric of the White Tower from 22.7-23.5m aOD. This hiatus was identified by a change in mortar in the steps and lies at roughly the same height as the mortar change seen in the surrounding turret wall which is also marked by ashlar blocks to stone rubble construction. The medieval mortars were used as a levelling layer beneath, on top of and along the vertical faces of each stone step. Remains of black carbonised wood impressions on the surface of the mortar show that the steps had been covered with timber boards.

1.1.3 Although malmstone was the principal stone-type associated with the medieval steps, it was not used above the building break. A large quantity of Caen stone, Reigate stone, and Quarr stone from the Isle of Wight, were used in the steps approaching the building break. These all displayed crisp axe carving suggesting an influx of better quality materials and artisans, which is in keeping with other rooms of the White Tower. Above the building break, Reigate stone was the most common rock type, with the continued widespread use of Quarr stone and localised use of Bembridge Limestone from the Isle of Wight. Roman ceramic building material was found in both late 11th century mortar types. Medieval ceramic building material was not found because it only began to be manufactured in London after 1135.

1.1.4 The Basement Level steps were constructed during the 1729 to 1753 alterations. The lowest four steps are timber and were supported by a brick wall dating to 1732-1734 when brick vaults were inserted in the basement. The 15 steps above are made of high quality cut paving blocks of polished Portland stone, Purbeck limestone and Hopton Wood marble all common late post-medieval (1700-1900) paving stone types.

1.1.5 The watching brief established that older timber covers still exist over Step 90 to 105 at Gallery Level, which had been recorded during the (Phase 1) watching brief in 2016. The oak covers below Step 90 were late 20th century in appearance with steel nosings housing grit treads. The timber boards had been glued tighter and secured with cross head screws. Faint graffiti on one of the timber treads of '1971' may suggest the date that they replaced the earlier scheme. Graffiti on one step showed that it was lifted on 04/04/1991. Datable finds under the covers included a 1960 shilling, 1995 and 2001 tickets and a 2007 tourist leaflet.

2 INTRODUCTION

2.1 Background

2.1.1 Pre-Construct Archaeology Limited was commissioned by Historic Royal Palaces to undertake historic building recording and watching brief in connection with the replacement of the protective timber staircase in the Flamsteed Turret at the north-east corner of the White Tower, Tower of London, London Borough of Tower Hamlets (**Figures 1** and **2**). The Flamsteed Turret is one of the four turrets at the corners of the White Tower and is centred on Ordnance Survey National Grid Reference (NGR) TQ 33633 80568. The historic building recording and watching brief was carried out in accordance with a Brief (Roberts with Spooner, 2017) and a Written Scheme of Investigation (Matthews, 2017). The scope of the works included undertaking an Historic England Level 2 photographic survey of the *in situ* timber covers prior to the commencement of works. Following the removal of the timber covers, a Level 3 survey including a petrological assessment of the stone staircase was carried out. This process included identifying the geologically source of stone or recommending suitable replacement stone to be used in the repairs of some of the steps between the Basement and Entrance Level. No repairs were undertaken to the other stone steps at Entrance Level and above, which were re-covered with timber.

2.1.2 The Tower of London is a UNESCO World Heritage Site (No. 488) and a Scheduled Monument (Greater London SM No. 10). The White Tower lies within the boundaries of these designations at the centre of the Tower of London. Designations of this level recognise that the Tower of London and its buildings are of international significance. The Tower also lies in the Tower of London Conservation Area.

2.1.3 The Tower of London's Conservation Management Plan lists the White Tower as being of exceptional significance. UNESCO's decision to award World Heritage Site status to the Tower of London, was in recognition of this significance. Gregory (2015) states that 'The White Tower is the example par excellence of the royal Norman castle in the late 11th century'. In addition to World Heritage Status, the White Tower is also designated as a Grade I listed building. It is described in its listing citation as follows:

'Tower keep. c.1078-1100 for William I and William II, probably to designs of Gundulf, Bishop of Rochester; later repairs and alterations, principally in C18 and C19 and by A Salvin, 1856-7; Rag-stone rubble with Caen stone dressings later replaced by Portland stone; lead roofs. Rectangular plan with apsidal projection at south-east angle housing east end of chapel, and cylindrical north-east stair turret. Anglo-Norman style. 3 storeys and basement, with 5-storey angle turrets. Each elevation (4-bay to north and south, 3-bay to east and 5-bay to west) has crenellated parapet, offset flat pilaster buttresses defining each bay and second-floor windows set in round-headed recesses forming bold Romanesque arcading; late C19 windows and early C19 sashes set in early C18 semicircular arched architraves with keyblocks, and impost

blocks to large first and second- floor openings. Two early C18 panelled double doors set in similar architraves to first floor of north elevation, late C19 double doors to west and approached by double-flight of steps to east; two late C11 round-arched lights to first floor; apsidal south-eastern projection (to chapel) has mid C19 Norman-style round-arched windows with engaged shafts; south elevation has similar windows to chapel, early C18 architrave to original late C11 entrance to west bay of first floor, and 2 pairs of late C11 round-arched windows set within larger round-arched recesses to third floor. Angle turrets have restored late C11 round-arched lights and weathervanes to cupolas.

Interior: each floor divided into two compartments by off-centre spine wall running north to south and by east-west wall defining area of chapel. All floors served by vice in north-east turret; vices from second floor in north-west and south-west turrets; inserted C14 vice in south wall, serving chapel.

Basement, former storage and service area, has brick piers and vaulting of c.1730, original well, round-arched doorway to barrel-vaulted sub-crypt, and traces of original splayed recesses for loops in south, west and north walls.

First floor: west compartment, former great hall, has C18 timber posts supporting ceiling, 5 round-arched embrasures and remains of late C11 round-arched fireplace along west wall, round-arched doorways flanking 3 tall round-arched recesses later pierced to make entries along east spine wall and round-arched embrasure to south altered into entry to inserted C14 vice; round-arched doorways to two garderobe chambers in north wall; east compartment, also with C18 timber posts supporting ceiling, has restored round-arched doorway to north-east vice, 3 round-arched embrasures and remains of round-arched fireplace along east wall and restored doorway set in wide round-arched recess to south-east crypt, which has had barrel vault restored in C20, 3 embrasures restored in C20, restored east window in niched apse, restored round-arched recess to west wall and restored round-arched doorway to square mural chamber in north wall.

Second floor, containing royal hall, chapel and chamber, originally rose two phases (the third floor being an early C17 insertion) with mural gallery and 5-bay round-arched arcade to spine wall at third-floor level: Main western compartment, former great hall with central hearth, has 9 round-arched embrasures, 2 restored round-arched doorways in spine wall, and original round-arched embrasure to south altered into entry for inserted C14 vice; mural passages to other vices.

East compartment or former royal chamber, has 3 tall round-arched recesses later pierced to make entries along west side of spine wall; round-arched entry to garderobe, window embrasure enlarged in C14, and round-arched doorway to garde-robe in north wall; late C11 chamfered round-arched fireplace and 3 round-arched embrasures in east wall; round-arched doorway to chapel.

Chapel of St John: aisled plan with eastern apse and ambulatory, of 13 bays; groin vaulting to aisles and ambulatory, with bays defined by responds forming arcade on outer walls and columns to main arcade surrounding barrel-vaulted nave which rises two storeys with barrel-vaulted triforium to upper stage; important series of Anglo-Norman capitals, including eight block-shaped capitals with fluted chamfers, one primitive Corinthian capital, two with primitive volutes, one cushion capital and two double-cushion capitals; all have scribed mouldings to abaci, except geometric carving to two western capitals, and eleven capitals have Germanic-inspired Tau crosses. Round-headed recesses to west wall, including inserted doorway to C14 vice.

Chapel restored by A Salvin in 1864-6, when windows (with C18 stained glass from Strawberry Hill) were replaced'.

2.1.4 Historic Royal Palaces, as custodian of the Tower, seek the agreement of Historic England regarding any repairs, improvements or alterations that may impact upon historic fabric. Scheduled Monument Consent has been granted by Historic England for the improvements to the staircase. The recording was carried out before and during the replacement of the timber staircase as a condition of this consent.

2.2 Scope of the Project

2.2.1 Concerns over the use of the Flamsteed Turret as the main fire escape route out of the White Tower has led to HRP deciding to replace the wooden steps, which cover its medieval vice. The topmost flight of steps leading to the Flamsteed turret rooms from mid-way between the Gallery Level and Roof Level was not included as part of this project.

2.2.2 The run of exposed stone steps and landings between the Basement and Entrance Level were repaired. The worn parts of these stairs were removed and replaced on a like-for-like basis using suitable replacement stone identified and recommended by Kevin Hayward, PCA's Petrologist.

2.2.3 The timber cover replacement scheme took place in a single programme of work, from January to June 2018. The project has provided a unique opportunity to scan and record the entire vice of the Flamsteed Turret, as well as recording its petrology. The whole staircase was not exposed in one go. It was uncovered and made available for recording in four stages within the programme of work.

2.2.4 HRP's curators required historic building recording of the treads and risers of the Flamsteed Turret's staircase, including its petrology. This was to consist of an Historic England Level 2 survey of the timber treads (Steps B1 to B4, 1 to 106, G1 to G6) before their removal and then a Level 3 survey of the stone steps below, including a petrology survey. This was also to include a Level 3 recording and petrology survey of the exposed stone steps leading down into the basement. The archaeologist was also required to undertake a watching brief during the project.

2.3 Historical Background of the Flamsteed Turret Staircase

2.3.1 Construction of the White Tower began around 1075-1079 and was completed after a hiatus in construction by 1100. When first built, the Flamsteed Turret's great stair was the only means of communication between all of the floors of the White Tower.

2.3.2 The turret assumed its name as a result of its association with John Flamsteed, the first Astronomer Royal, who made some of his earliest astronomical observations from the roof of the White Tower.

2.3.3 The staircase has remained in regular use to the twenty-first century, and it still provides the only access to the Tower of London's roof. The small office at the top of the staircase was used as the office for the Master of the Royal Armouries in the early-twentieth century.

2.3.4 Due to this regular use the original stone steps have been covered with a protective wooden surface since at least 1821 (**Figure 15**).

2.4 Previous Archaeological Investigations

2.4.1 Two watching briefs have taken place on areas of the staircase which have been exposed to help develop the current works. The first of these, TOL 128, took place in October 2012. The areas, which were exposed, allowed for the identification of two building phases for the staircase, which appeared to relate to the known break in the White Tower's construction. The steps were identified as being predominantly constructed of Kentish Ragstone. The lower steps were placed against Caen ashlars and were found to be in good condition, possibly suggesting they had replaced earlier Reigate stone treads. The treads on the higher area of steps were identified as being in poor condition (Keith-Lucas, 2012).

2.4.2 In November 2016, TOL 165 recorded the stone stairs which were exposed between the second floor and the roof during trial works for this project. Here again the steps were believed to have been made from Kentish Ragstone, although several areas of repair could be identified, including re-used tiles and concrete (Stevenson, 2017).

3 METHODOLOGY

3.1 Aims and Objectives

3.1.1 The research aims and objectives of the historic building recording and the watching brief as set out in the Brief (Roberts with Spooner, 2017) were as follows:

General Aims

- To record the stairs of the Flamsteed Turret, before and after the removal of the protective covering.
- To prepare a fully illustrated report on the results of the historic building recording and watching brief that was proportionate to the findings and compliant with all relevant regulations, policy, guidance and good practice.
- To archive all documents, material and digital records created as a result of any archaeological investigations (associated with the building recording and watching brief) with Historic Royal Palaces.

Specific Objectives

- To record the current protective wooden steps prior to their removal.
- After the removal of the protective layer, to complete a stone-by-stone petrological analysis of the exposed stairs in the Flamsteed Turret
- To include mortar samples in the analysis. The number of samples was to be agreed between the HRP curator or HRP's Assistant curator for archaeology and the contractor.
- To understand the phasing and dating of the construction of the stairs as well as any alterations to the fabric.
- To identify and answer other questions that arise during the programme of historic building recording

3.2 Documentary Research

3.2.1 No research of primary resources was undertaken.

3.3 On-Site Recording before removal of the timber covers

3.3.1 The stair numbers and levels used during the project were those provided by HRP on architect's drawings (**Figures 3** to **5**). The historic building recording, watching brief and all petrological work (including all petrological drawings) used these plans as base drawings (**Figures 3** and **4**).

3.3.2 Recording of the timber covers (treads, risers and nosings) was carried out before they were removed in accordance with a Level 2 Survey as defined by Historic England (Historic England, 2016). Step B1 at Basement Level up to Step 25 just above Entrance Level and

Step 73 just below Gallery Level up to Step 106 just below Roof Level were recorded on 02 January 2018. Steps 26 just above Entrance Level up to Step 72 just below Gallery Level and Step G1 at Gallery Level up to Step G6 just above Gallery Level were recorded on 08 January 2018.

3.3.3 A photographic survey comprising high resolution digital images of the *in situ* timber covers was completed. In addition, a photographic survey by Robin Foster was also provided. A selection of PCA's and Robin Foster's photographs has been included as plates in this report and **Figures 35** to **41** show the location and direction of these photographs.

3.4 On-Site Recording during removal of the timber covers

3.4.1 The timber protective steps were removed in four stages (**Figure 3**).

- **Stage 1** was carried out from Step 21 at the Entrance Level down to Step B1 at the Basement Level
- **Stage 2** was carried out from Step 50 at the Upper Level down to Step 22 at the Entrance Level
- **Stage 3** was carried out from Step 76 just below the Gallery Level down to Step 51 at the Upper Level
- **Stage 4** was carried out from Step 90 just above the Gallery Level down to Step 77 just below the Gallery Level and Step G1 at Gallery Level up to Step G6 just above the Gallery Level

3.4.2 The building contractors removed the timber covers in this order because it was not possible for them to remove the covers from the base of the staircase upwards. This was because each riser was screwed in place from the underside of each tread. As a result, each stage started from a landing area where an initial stair could be removed.

3.4.3 Wood glue, Superglue and PVA had been used to attach lengths of treads and risers together. The building contractors removed these lengths by leverage between a tread and a riser using soft timber wedges or crowbar/chisel. The contractors took care not to damage the underlying stone steps or stone walls of the Flamsteed Turret when using these methods.

3.4.4 The visiting public normally use the stairs in the Flamsteed Turret (**Plate 1**) as the main exit from the White Tower. During the works, an external scaffold staircase was erected against the north elevation of the White Tower for this use so that the stairs in the Flamsteed Turret could be isolated for the renovation work (**Plates 2** and **3**). The Stage 1 works were carried out before the external scaffold exit from the White Tower had been completed. In order to isolate Stage 1 (Steps 21 down to B1) from the public and exhibitions, a temporary dust barrier was erected at Step 23 (**Plates 4** and **5**) and another at the base of the steps near Step B1. Step 21 was chosen as the first cover to be removed (**Plate 28**). The nosing and riser screws were removed from this step and a chisel used to separate the glued pieces, which allowed the tread to be removed. Following the removal of the timber tread for Step 21

(**Plates 18** and **19**), the timber tread for Step 20 was removed (**Plates 30** and **31**).

3.4.5 Following the removal of a cover or length of covers, each stair was photographed (**Plates 6** and **29**). The archaeologist then conducted a search of the remains below the covers so that any material of interest could be retained. Each find was bagged by step number, however since all the finds were modern, none were retained. A few were photographed (**Plates 34, 41** and **42**). The building contractors then cleaned the stairs with a dustpan and brush and vacuum cleaner. High-resolution digital photographs of every step are included in the archive and a selection has been included in this report.

3.4.6 The watching brief during the removal of the timber covers was undertaken from 03 to 05 and 22 January, 02, 05, 26 to 28 February, 01 and 05 March and 05 June 2018.

3.5 On-Site Recording after removal of the timber covers

3.5.1 After the timber covers had been removed and the stone steps had been cleaned, all modern fixtures were removed from the steps apart from a modern screw in Step 78, which was left *in situ* because its removal might have damaged the stone step (**Plate 52**). The stairs were then recorded to the standards of a Level 3 survey (Historic England, 2016) and a petrographic survey was undertaken. A photographic survey comprising high resolution digital images was undertaken after the timber covers had been removed as well as during the installation of the new protective covering.

Petrographic Survey

3.5.2 A detailed and comprehensive stone-by-stone petrographic survey of the staircase was undertaken working up the stairs step-by-step.

3.5.3 The earliest stage of work was carried out in January and February 2018 and related to the repair of the stone and brick steps from Step B1 at Basement Level up to Step B19 (Landing 3) mid-way between Basement Level and Entrance Level (**Figure 3**). The architect made an additional request for this stage of the petrological work. This was to geologically source and identify or recommend suitable replacement stone for the worn nosings (edges of the steps) on stone treads on Steps B5 to B7, B18 and B19 (Hayward, 2018). These steps had become worn as they have not been covered with protective wooden cladding (**Plates 8** and **12**). This necessitated the replacement of the nosings of these stairs through the creation of an indent in the stonework (through removal of the worn section of a step) which was refaced using a suitable replacement stone type identified during the course of works (**Plates 13**).

3.5.4 The next stage of work was carried out in March and June 2018 and related to the replacement of the timber covers of the medieval steps from Step 1 (Landing 3) mid-way between Basement Level and Entrance Level up to Step 90 (Landing 6) above Gallery Level and included the Gallery Steps: Step G1 at Gallery Level up to Step G6 (Landing 6) above Gallery Level (**Figure 3**).

3.5.5 Architects plans of the steps were initially annotated with stone and mortar types. This

information was later transferred to full photogrammetric plans and elevations of the steps supplied by HRP (**Figures 19** to **34**). Identifiable building phases and significant features were also recorded.

3.5.6 The identification of the primary late 11th century medieval steps, which had been built in two phases, was considered a primary task. The key objective here was to identify the 1080-1090/93 break in the construction of the White Tower seen in earlier work (Impey, 2008) as a distinct change in mortar type at 22-23m aOD (above Ordnance Datum). Post-medieval repairs and builds, including the construction of the steps at Basement Level were studied in the same level of detail. All stone types, ceramic building materials and mortar present in the steps of the Flamsteed Turret were recorded. Dr Kevin Hayward, PCA's petrologist, identified the *in-situ* fabric using a Gowlland x10 magnification hand lens (**Plates 13** and **64**). The petrographic survey was in accordance with the standards of a Level 3 survey (Historic England 2016) and similar to those carried out during conservation work at the Devereux Tower (Palmer & Shaffrey 2011), the Develin Tower (Hayward & Garwood, 2015), the Bell Tower (Hayward, 2016), the Well Tower (Hayward, 2017a) and the Wardrobe Tower (Hayward, 2017b).

Stone Identification

3.5.7 Detailed stone-by-stone geological identification of the medieval and post-medieval stone was undertaken. Fragments of stone, completely detached prior to the timber staircase replacement work, were sampled for hand specimen comparative analysis under the binocular microscope. Eight samples of stone (S1 to S8) were taken; their location is shown on **Figures 19**, **21**, **25**, **29**, **31** and **33**. It has been shown from previous conservation projects that detailed visual analysis of stone type and geological source can support the analysis of building phases, development, repair and alteration. This is because different rock types were used in particular archaeological and historical periods. **Figures 19**, **21**, **23**, **25**, **27**, **29**, **31** and **33** show the identification of stone types within the steps in the Flamsteed Turret. The stone types are described in **Appendix 1**.

Ceramic Building Material Analysis

3.5.8 Brick, medieval and post-medieval peg tile and fragmentary Roman tile were mainly analysed *in-situ* using the system of ceramic building material classification used in archaeological work in Greater London. Three samples of tile (CBM1 to CBM3) were taken; their location is shown on **Figures 20**, **24** and **34**. Each fabric number (e.g. fabric *2452*) specifies the composition, form, approximate method of manufacture and date range of the material. Examples of the brick fabrics can be found in the archives of the Museum of London and PCA. The ceramic building material types are described in **Appendix 1**.

Mortar sampling and Analysis

3.5.9 Different types of facing and bedding mortars were identified *in-situ* in the steps and marked on the architect's drawings and later the photogrammetric drawings. A record was made of

the mortar types initially by visual inspection of hand specimen by the petrologist and any diagnostic inclusions such as oyster shells noted. Twelve samples of bedding mortar (M1 to M12) were taken; their location is shown on **Figures 20**, **22**, **24**, **26**, **28**, **30**, **32** and **34**. These were examined under a greater magnification using a binocular microscope.

3.5.10 The key objective of the analysis was to identify a change in mortar type, seen elsewhere in the Tower at 22-23m aOD (Impey 2008), which occurred immediately after the building break of 1080 to 1090/93. It has been shown from previous conservation projects that detailed visual analysis of mortar colour, fabric and inclusions assist in identifying phases of building construction. **Figures 20**, **22**, **24**, **26**, **28**, **30**, **32** and **34** show the identification of mortar types within the steps in the Flamsteed Turret. The mortar types are described in **Appendix 2**.

3.6 Project Archive

3.6.1 The project archive is currently held at the offices of Pre-Construct Archaeology Limited in Brockley, London, under the site code ToL 169 and accession code (3910079). Both codes have been provided by HRP. The project code has been written on all records and sample containers, whilst the accession number has been written on the top-most sheet of each bundle of photographic registers in the archive.

3.6.2 It is anticipated that the archive (copies of the report, photographic registers and photographs) will be lodged with Historic Royal Palaces. The report will be prepared as soon as possible after completion of the on-site work and a copy will be submitted to Historic Royal Palaces and the GLHER (Greater London Historic Environment Record).

3.7 Guidance

3.7.1 All works were undertaken in accordance with standards set out in:

- CIfA (2014) *Standard and Guidance for the Archaeological Investigation and Recording of Standing Buildings or Structures* Chartered Institute for Archaeologists
- English Heritage (now Historic England) (2005) *The Presentation of Historic Building Survey in CAD*
- Historic England (2015) *Guidelines for Archaeological Projects in Greater London* Greater London Archaeological Advisory Service
- Historic England (2016) *Understanding Historic Buildings; a guide to good recording practice*

4 HISTORICAL BACKGROUND

4.1.1 The following historic background has been mainly taken from the Brief (Roberts with Spooner, 2017).

4.1.2 The Flamsteed Turret is the north-east of the four turrets at the corners of the White Tower, which lies at the centre of the Tower of London. The White Tower formed the Keep to the medieval fortress of the Tower of London. The castle, which later became known as the Tower of London, was begun by William the Conqueror in 1066. It began as a timber fortification enclosed by a palisade. In the next decade work began on the White Tower, the great stone keep that still dominates the castle today. The precise date of the White Tower's foundation is unknown, and it is also uncertain how long building took. It is traditionally held that construction began in 1078. This is because the *Textus Roffensis* records that Gundulf, Bishop of Rochester, oversaw the building work under instruction from William the Conqueror. Dendrochronological evidence suggests construction of the White Tower began in 1075–1079. The archaeology of the standing building suggests there was a pause in construction between 1080 and 1090–1093, although it is unknown why. Gundulf did more than just oversee work and was a skilled architect. Rochester's castle and cathedral were rebuilt under his auspices. As the main castle in England's capital, the Tower of London was an important royal building. The keep built by Gundulf bears testament to this as it was one of the largest in Christendom. The White Tower was completed by 1100.

4.1.3 The fortress was constructed within the south-eastern corner of the ancient Roman city walls, along the riverbank of the Thames. It measures 118ft x 106ft, rising to a height of 90ft on the south side with walls up to 15ft thick at its base (Impey and Parnell, 2000). During the medieval period it was in use as a Royal Hall and Chamber and the Chapel of St John.

4.1.4 The White Tower is the earliest stone keep in England and was the strongest point of the early castle. It also contained grand accommodation for the king. When originally constructed, the White Tower comprised three basic levels, with a basement, the principal entrance or ground floor and the first floor. The tower was terraced into the side of a mound, so the northern side of the basement is partially below ground level. As was typical of most keeps, the basement was an undercroft used for storage. The entrance floor was probably intended for the use of the Constable of the Tower, Lieutenant of the Tower of London and other important officials. The upper floor contained a grand hall in the west and residential chamber in the east – both originally open to the roof and surrounded by a gallery built into the wall – and St John's Chapel in the south-east.

4.1.5 Royal activity at the castle in the early 14th century declined relative to previous periods. Though the Tower of London was still occasionally used as a residence, by the 1320s the chapel in the south-east corner of the White Tower was used to store records. This marked the beginning of the castle's diminishing role as a royal residence. It may have been during

the reign of Edward III (1327–1377) that buildings abutting the south and east side of the White Tower were created. Built as storage, they may have been part of Edward's building programme at the Tower of London, which saw its role as a military store come to the fore.

4.1.6 The second floor (Gallery Level) of the White Tower was a later addition added in the late 15th century during the reign of Henry VII (1485-1509) to create extra storage. At this time, the earlier medieval roofs were removed, and the present nearly flat roofs built one storey higher just below the false (tall parapet) walls and battlements of the Norman Keep. Dendrochronology has shown that this raising of the roof level and insertion of a new second floor occurred *c.*1490. The present late medieval roof survives as one of the most outstanding features of the White Tower, covering almost a quarter of an acre in area and built in a late medieval design, typically found in 15th and 16th century church roofs. It incorporates exceptionally large timbers, sourced from the Kings Royal Forests, with tie beams within the western chamber in excess of 43ft in length and at a scale unprecedented in England.

4.1.7 During the 15th and 16th century, the White Tower was used for the storage of munitions and less for Royal lodgings and formal occasions such as the ceremony of the Knights of Bath. The White Tower is labelled 'W" on Haiward and Gascoyne's plan of the Tower in 1597 (**Figure 7**). Three piles of cannon balls(?) appear to be stored on the ground close to the north-east turret (later known as the Flamsteed Turret). The Wardrobe Tower is labelled "Y" on this plan to the south with the 'Jewel House' in front of the White Tower. This plan also shows an east annex to the White Tower with the 'Queen's Lodging's' to the south. By the 17th century the whole of the top (second) floor was set aside for the storage of gunpowder (Miles, 2007).

4.1.8 John Flamsteed was born in Denby, Derbyshire in 1646 and came to London in February 1675, where he stayed at the Tower of London. He became the First Astronomer Royal in March 1675 and in June 1675 laid the foundation stone of the Royal Greenwich Observatory. He used the north-east turret of the White Tower as the first Royal Observatory before the Royal Greenwich Observatory was completed. It was later named the Flamsteed Turret after him. Flamsteed catalogued many thousands of stars.

4.1.9 Holcroft Blood's 1688 'birds-eye' view of the Tower of London (**Figure 8**) shows the White Tower with the circular Flamsteed Turret and the Wardrobe Tower at the south-east corner of the eastern annexe to the White Tower.

4.1.10 The layout of the basement has remained the same since the tower's construction, although in the 18th century its floor was lowered and the pre-existing timber vaults were replaced with brick counterparts. Early 18th century plans show that the basement of the White Tower was used for the storage for salt petre and gun powder and that access to the salt petre vaults was through the Flamsteed Turret at Basement Level (**Figures 10** and **11**). The original connection between the Flamsteed Turret and the White Tower is shown on early 18th century plans (**Figures 9** and **10**) and was similar to that still extant at Entrance Level (**Figure 4**). By

1754, this connection appears to have been altered to that extant today and a doorway had been added in the north wall of the Flamsteed Turret that still exists (**Figures 4** and **11**; **Plate 1**). These changes appear to be part of the 1729 to 1753 alterations, presumably to facilitate access to the salt petre stores. The east access from the Flamsteed Turret to the eastern annexe of the White Tower has since been blocked and a new south-east opening has been made in the Flamsteed Turret (compare **Figures 4**, **9** to **11**).

4.1.11 A 1754 Entrance Level (Ground Floor) plan of the White Tower shows that the Flamsteed Turret had a similar layout as today apart from an opening overlooking the eastern annexe that has since been blocked (compare **Figures 4** and **12**). This plan shows the Entrance Level of the White Tower was used for the 'Sea Armoury' with 'Chests for holding of Arms', 'Store Room for Tools, etc' and the chapel was 'Room where the Records of the Office of Ordnance are kept'. The eastern annexe is labelled 'Old Drawing Rooms', 'Room where the Records of the Office of Ordnance are kept', 'Book Binding Room' and 'Store Room where Cartouch(Cartridge)-Boxes are kept'. Work to the White Tower's eastern annexe had taken place in 1715-1716 when it was converted for use by three Ordnance departments; the Drawing Room, Record Office and Modelling Room (Parnell, 2014 122-128).

4.1.12 William James' plan of the Second (Gallery) Floor of the White Tower dated 1754 (TNA WORK 31/102; **Figure 13**) shows the medieval stair vice in the Flamsteed Turret with two arrow slits and the Gallery Steps (G1 to G6) to the west. A doorway has since been inserted in the south wall of the Flamsteed Turret (compare **Figures 5** and **13**). This plan shows the Gallery Level of the White Tower with a 'Store Room where Match-Rope, Wheelbarrows, Shovels, etc are kept', 'Room where part of the Records of England are kept' and 'Gallery over Chappel where part of the Records are kept'.

4.1.13 Frederick Nash's 1820 lithograph of White Tower (**Figure 14**) shows the eastern annexe with its north wall butting up against the Flamsteed Turret. This view shows the central window in the north wall of the eastern annexe at Entrance Level had been converted into a doorway with steps leading up to it (compare **Figures 12** and **14**). A *c.*1821 and 1851 view of the vice in the Flamsteed Turret (**Figures 15** and **16**) show the medieval stair vice with timber coverings. The 1872-73 Ordnance Survey map (**Figure 17**) shows that a connection had been made between the Flamsteed Turret and the eastern annexe at Entrance Level, which has since been blocked.

4.1.14 By the mid-nineteenth century, the influence of the Board of Ordnance at the Tower of London began to diminish, and its departments began to be re-located elsewhere, leading to a long-running campaign led by the architect Anthony Salvin to re-medievalise the site (Parnell, 1993, 98-108; Parnell, 1998). Salvin led a campaign to restore several of the Tower's buildings, including the White Tower. After his retirement, leadership of the Office of Work's restoration project was taken over by John Taylor who proposed that the eastern annexe of the White Tower should be demolished. In 1876 the annexe's western wall was

found to be in poor condition, and although the older eastern wall was found to be better condition, it was believed to be only a matter of time until it would need to be re-built. Taylor's decision was based on his opinion that its removal would allow the White Tower to be seen in its original condition (Keay and Harris, 2008, 213). The majority of the eastern annexe was demolished in 1879 (*ibid*. 213), however during the course of the demolition the remains of the medieval Wardrobe Tower were exposed, along with traces of the Roman city wall onto which it had been built. These remains are still extant at the south-east corner of the former eastern annexe and are labelled on the 1896 Ordnance Survey map (**Figure 18**).

5 TIMBER STAIRCASE

5.1 Introduction

5.1.1 A timber staircase has covered the stone steps of the Flamsteed Turret since at least 1821 and is depicted again in 1851 (**Figures 15 and 16**).

5.1.2 This section of the report describes the timber covers, which were removed as part of renovation of the staircase in the Flamsteed Turret in 2018. Recording of the timber covers before removal was undertaken on Steps B1 to B4, Steps 1 to 90, Steps G1 to G6 and Steps 91 to 106 (**Figures 3** to **5**). The watching brief during removal was undertaken on the same stairs apart from Steps 91 to 106.

5.1.3 The Flamsteed Turret (**Plate 1**) has a spiral staircase which accesses six floors (Basement, Entrance Level, Upper Level, Gallery Level, Roof Level and Observatory Level (**Figures 3** to **5**). Three mid-levels (Mid-Level Entrance to Upper, Mid-Level Upper to Gallery, Mid-Level Gallery to Roof) enable each step to be shown on a plan.

5.1.4 The following is a description of the timber staircase from the basement upwards from Step B1 to Step 106.

5.2 Steps B1 to B19

5.2.1 The treads and risers of Steps B1 to B4 (**Figures 3** and **4**) were constructed from oak boards (**Plate 7**), while stone Steps B5 to B19 had not been covered with timber (**Plate 8**).

5.2.2 The machine-cut timber boards covering Steps B1 to B4 are 20th century in appearance. The use of steel nosings, modern cross-head countersunk screws, modern glues (such as superglue and wood glues) suggest a late 20th century date for their construction (**Plate 7**).

5.2.3 Steps B1 to B4 comprised a straight flight of four east-west timber stairs that did not cover earlier stone steps (**Plate 9**). Step B4 (Landing 1) comprised five north-south floorboards (5cm thick) supported by three east-west machine-cut floor joists, which were 20th century in appearance (**Plates 10**). These joists were not secured and were held in position by the overlying oak boards, which were fixed using 6cm modern cross-head screws. The western joist was more recent in appearance (perhaps dating from the time that the modern risers and treads were added).

5.2.4 The four steps had been secured to two visibly older timber strings using modern 12cm countersunk cross-head screws. The two strings may date to the early 18th century when the basement was lowered as these steps are shown on plans of this date (**Figures 10** and **11**). It is possible that the four timber steps were originally constructed during the same period as the extant timber covers on Steps 90 to 106 (**Figure 3**; **Plate 9**).

5.2.5 The joists were in turn supported at their west end by a north-south brick sleeper wall, which was constructed with red bricks. The south wall of the void under Step B4/Landing 1 was

constructed in similar brickwork. This brickwork dates to 1732 to 1734 when brick vaults were inserted in the basement (Harris, 2008, 63). The north wall of the void was constructed in large pieces of Kentish Ragstone laid during the initial construction of the White Tower. The void below Step B4/Landing 1 contained a considerable amount of broken glass and multiple wires (suggesting the covers have been removed multiple times) (**Plate 11**).

5.2.6 Steps B5 to B19 were not covered with protective timber covers and grit treads had been attached to these stones with adhesive (**Figures 3** and **4**; **Plate 8**).

5.3 Steps 1 to 90

5.3.1 Steps 1 to 90 form the bulk of Flamsteed Turret's steps rising from Landing 3 mid-way between Basement and Entrance Level up to Landing 6 just above Gallery Level (**Figures 3** to **5**). They were covered with similar oak treads and risers as those covering Steps B1 to B4 and are thought to date to the mid to late 20th century. They appeared to be in relatively good condition given the considerable footfall that they have received (**Plates 14** to **17**).

5.3.2 The underlying stone Steps 1 to 90 are part of the medieval spiral stair vice in the Flamsteed Turret. The timber treads measure approximately 10cm at the newel and 60cm at their outer circumference. The oak boards were approximately 5cm thick. The treads of Steps 1 to 89 were constructed from multiple planks of oak that had been glued together using various types of glue (**Plates 18** and **19**). In addition, the timber treads and risers had been glued together.

5.3.3 A steel nosing with a grit tread had been attached to each timber tread with modern 3cm countersunk cross-head screws. Beneath each grit tread, modern 6cm cross-head screws had been used to secure the tread to the riser below. Each tread was attached to two risers (front and rear) resulting in each riser being screwed into place from above and below. This meant that each tread had to be removed with its surmounting riser attached. A varying number of screws had been used on each tread with many showing obvious signs of removal and re-use. In addition, empty screw holes for the risers of many steps suggest that the covers had been lifted and replaced at different times (**Plate 22**).

5.3.4 Softwood wedges had been hammered in at irregular intervals on both sides of the treads, beside the wall and newel (**Plates 16** and **17**). These wedges were added sometime after the timber staircase had been constructed to improve the structural tension of the timber treads, which were not keyed into the historic fabric of the turret. The movement of the timber treads due to the heavy footfall had caused the wedges to rub on the outer wall and newel of the turret (**Plates 17, 20** and **21**). No wedges had been used on Step 90 and above because these covers had been individually made to fit each stair in contrast to the same sized treads and risers used for the timber covers below.

5.3.5 Upon removal, it was apparent that the treads were not fitted exactly with the stone steps beneath with a difference of between 4 and 39cm between the timber risers and that of the

stone steps (**Plate 23**). Some movement of the timber staircase may have taken place where it was not secured to the stone steps.

5.3.6 Some of the timber treads had been screwed into irregular timber inserts, which had been hammered into the mortar between the stones of the medieval treads (**Plate 24**). Timber inserts had been driven into Steps 2, 9, 10, 14 to 18, 21, 22, 24, 25, 32 to 34, 51, 54, 57 to 59, 66, 67, 74 to 76, 79, 80, 83, 87 and 88 (**Plates 38**, **39**, **45** and **70**). A timber insert appears to have been removed from the mortar between stones in Steps 35 and 74 leaving a void (**Plate 45**). The timber inserts were unrelated to the current timber covers and were associated with a previous covering of the steps. A late 18th/early 19th century rose head nail was found in a timber insert in Step 20 (**Plates 33** and **34**) and it is probable that the timber inserts were originally hammered into the mortar between the stones in the late 18th/early 19th century. The spread of these timber inserts across Steps 1 to 89 and the evidence obtained from the Phase I removal of the timber covers from Step 90 to 106 (which had been nailed into the timber inserts in the staircase) suggest that similar timber covers to those that cover Steps 90 to 106 once also covered Steps 1 to 89.

5.3.7 In one instance, a previous contractor had screwed a modern screw into a stone tread at Step 78 (**Plate 52**). The screw could not be removed without damaging the stone and was left *in-situ*.

5.3.8 The timber treads were mostly freely sitting upon rubber pieces on timber cut-offs. The rubber pieces were attached to the base of the timber treads while the timber cut-offs were placed directly on the stone steps resulting in a disproportionate amount of force transferring onto the stone steps below at localised points (**Plates 25** to **27**).

5.3.9 Dust and debris had collected on each stair below the timber covers (**Plates 32, 46** and **47**). Finds were generally discovered on the outer circumference of the spiral staircase, which is consistent with the items being dropped accidentally or possibly 'posted' into the covers by a child. A slightly worn shilling, worth five pence and dated 1960, was found under the timber cover on Step 34 (**Plates 40** to **42**). Shillings were taken out of circulation in 1990. A small faded graffiti in pencil was observed on the soffit of the timber tread of Step 75, which simply read '1971'. A penny (1977), which does not appear to be particularly worn, was found on Step 16. A twenty pence piece (1987) was found on Step 18.

5.3.10 Graffiti had been written on the underside of Steps 14 and 16 in black felt tip pen (**Plates 36** to **37**). The graffiti on Step 14 reads: 'I hope this place falls down and the one winged ravins fly backways sh*tt*ng on the tourists, Derek Flanagan 4/4/91' (**Plate 37**), while that on Step 16 states: 'Up the I.R.A. United Ireland. Will the tans never learn. Barbaric pomy stuck up stiff upper lip shower of thieving w*nk*rs' (**Plate 36**). The similarity of the graffiti on the soffits of the timber treads of Steps 14 and 16 and the date of the graffiti on Step 14 suggests that these timber covers were lifted in April 1991.

5.3.11 A ticket to the Tower of London dated 10th June 1995 was found on Step 28 (**Plates 35** and **43**). Another ticket to the Tower of London dated 12th September 2001 was found during the removal of dust from Step 19 (**Plates 34** and **35**). A 2007 leaflet for the Tower of London was found on Step 48. It is highly unlikely that an entire leaflet fell under the structure of the stairs and was almost certainly placed during a phase of removal or posted into the covers.

5.3.12 A Tower of London gift coin depicting Henry VIII's armour was found on Step 18. Various pieces of modern plastic jewellery, including an entire plastic bracelet on Step 18, Tower of London gift coins, miscellaneous modern sweet wrappers, marbles and other pieces of refuse were discovered beneath the stair covers during the removal phase of the project.

5.3.13 A rifle round was found on Step 61 (**Plates 46** and **47**). Although, It was highly unlikely to have been a live piece of ammunition, the Tower of London staff removed it and it was disposed of safely. It was most likely a prop/fashion piece, which had fallen off someone's clothing.

5.4 Steps G1 to G6

5.4.1 Steps G1 to G6 are a straight east-west flight of stairs (**Figures 3** and **5**; **Plate 53**). Their timber covers were constructed of oak of the same date as those that covered Steps B1 to B4 and Steps 1 to 89. The oak covers were constructed from single timber boards. Steel nosings had been attached to the timber treads using 3cm and 6cm modern cross-head screws. The removal of these covers revealed that cement mortar and modern softwood had been used to try and secure them over the medieval stone steps (**Plates 54** and **86**). Timber inserts had not been driven into the mortar of this flight of steps.

5.5 Steps 90 to 105

5.5.1 The timber covers over Steps 90 to 105 (**Figure 3**; **Plates 55** and **56**) were recorded by the Historic Royal Palace's Curatorial Department during a watching brief (Phase I) when they were removed and re-laid in December 2016 (Stevenson, 2017, **Plate 57**). More dust and debris had accumulated on these steps than on those observed over Steps 1 to 89 during the current watching brief (compare Stevenson, 2017, figs 7&8 with **Plates 6**, **23** to **27**). This suggests that Steps 90 to 105 had not been lifted as recently as the timber covers over Steps 1 to 89. In addition, several torn pieces of newspaper dated 28th May 1938 were found beneath the timber tread on Step 105 (numbered Step 16 in Stevenson, 2017), which suggests 'the date of at least one phase of repairs' (ibid, 7).

5.5.2 This watching brief also showed that the method of construction of the timber covers using the timber inserts between the stones of the medieval treads was still in place prior to lifting the timber covers from Steps 90 to 105. At Step 92, three lengths of timber over the stone tread from front to back were secured via timber inserts between the mortar of the stones (**Plate 57**). The three lengths of timber were secured into notches cut into the top of the timber riser in front. The three lengths supported the timber tread above. Step 105 showed

the same method of construction for the timber covers with two lengths of timber running over the stone tread from front to back and secured via the timber inserts between the mortar of the stones (Stevenson, 2017, figs 5&7). Both lengths of timber were secured into notches cut into the top of the timber riser in front. The two lengths supported the timber tread above. This method of construction (notches at the top of the riser) was also visible in Steps 106 (numbered Step 17 in Stevenson, 2017) even though this timber cover was not lifted.

5.5.3 The timber covers over Steps 90 to 106 are earlier in appearance than those over Steps 1 to 89 (**Plates 55** and **56**). It is possible that the covers over Steps 90 to 106 date to the late 18th/early 19th century because the rose-head nails used in their construction date from the late 1780 to 1820. These nails were also found in the timber inserts beneath the 20th century covers (such as at Step 20; **Plate 33**), which suggests that the timber covers over Steps 1 to 89 were once the same as those over Steps 90 to 106 and had been replaced in the late 20th century.

5.5.4 Timber wedges at the sides of the timber covers had not been used above Stair 89, presumably because these covers had been individually made to fit each stone step rather than using a standard stair size as used for the late 20th century covers over Steps 1 to 89.

5.6 Observatory and Roof Steps

5.6.1 The Roof and Observatory levels were not recorded during the site visits however it is understood that similar timber covers to those over Steps 91 to 106 continue at these levels.

5.7 The replacement covers

5.7.1 Following the cleaning and repair of the stone steps (**Plate 58**), the contractors recovered them with new timber treads and risers. It was not possible for them to use traditional timber strings. In addition, the previous method of using irregular timber/rubber cut-outs as well as timber wedges had caused damage to the stone walls and steps of the Flamsteed Turret and therefore could not be repeated (**Plate 59**). The contractors made individual steel trays for each step to take the new oak covers (**Figure 6**).

5.7.2 The stone steps are not level or consistent in size. It was therefore necessary for the contractors to measure each step individually before constructing the steel frame (**Plate 60**). The steel trays of each step bolt into each other via protective zotefoam strips providing anchorage for the covers (**Figure 6**; **Plate 61**). Where a void existed between the steel tray and the stone step a barrier of cloth and prompt mix was used to protect the step while anchoring the trays safely (**Figure 6; Plate 62**).

5.7.3 The steel frame not only provides the necessary strength for the staircase to be used as the main exit of the White Tower, but also allows each oak panel to be removed individually if necessary to enable inspection of the historic fabric (**Plate 63**). Tailoring the steel framework to fit each step individually also removes the large voids that occurred with the previous timber covers (**Plate 23**). These large voids had allowed a significant build-up of dirt and

debris.

5.7.4 Steps B5 to B19 (**Figures 3** and **4**) were cleaned and repaired (**Plate 12**). The former grit treads, which had been attached directly to the stone, were removed and the worn nosings were replaced with new stone indents (**Plate 13**).

6 STONE STAIRCASE

6.1 Introduction

6.1.1 Following the removal of the timber covers, the fabric and mortar of 111 stone steps and the brick wall supporting Steps B4/Landing 1 were identified.

6.1.2 Three areas of the staircase were considered separately and placed in chronological order:

1. The medieval steps (Steps 1 to 90) starting with the lowest (earliest) at Landing 3 between the Basement and Entrance Level (Step 1) up the highest (latest) at Landing 6 above Gallery Level (Step 90)
2. The six Gallery Level steps (Steps G1 to G6) from Gallery Level up to Landing 6
3. The post-medieval steps (Steps B4 to B19) from Basement Level up to Landing 3 between the Basement and Entrance Level

6.1.3 The steps are grouped in the text according to similarities in their petrology, associated mortar, tool markings, form and size of blocks.

6.2 Medieval: Steps 1 to 90

6.2.1 Medieval stone and mortar fabric is present in the Flamsteed Turret steps from Step 1 to 90 (**Figures 3** to **5**, **21** to **34**; **Plate 65**). On the basis of mortar type it is possible to sub-divide the medieval staircase into two. First, those steps pointed by a dense shelly fawn mortar (Type 1 hereafter T1; **Figures 22**, **24**, **26**, **28** and **30**; **Plate 66**) found in Steps 1 to 66 and those pointed in the chalk rich cemented mortar (Type 2 hereafter T2; **Plate 67**) found in Steps 67 to 90 (**Figures 30**, **32** and **34**; **Plate 66**). Mortar T1 (**Appendix 2**) is identical to the early 1075/79 to 1080 mortar seen below roughly 22m-23m aOD of the external and internal elevations of the White Tower (Impey 2008). Mortar T2 (**Appendix 2**) is identical to the later 1090/93 to 1100 mortar seen above the 22m-23m aOD building break of the White Tower (Impey 2008). Each section of stairwell is considered in turn.

Steps 1 to 55: Medieval 1075/79 to 1080

6.2.2 There is considerable homogeneity in the stone types used in Steps 1 to 55, which consists of 217 individual paving slabs (**Figures 22**, **24**, **26**, **28** and **30**). The 55 steps stretch from Landing 3 between the Basement Level and Entrance Level up to just above Landing 5 of the Upper Level (**Figure 3**).

6.2.3 Steps 1 to 34, 37 to 56 have 178 stone pavers. A total of 82% of these pavers contain at least one example of a poor quality, light-cream grey muddy micaceous limestone (**Figures 22**, **24**, **26**, **28** and **30**; **Plate 68**) matched to malmstone (Upper Greensand) of the Selborne Group either at Alresford, Selborne and Farnham (Osborne-White 1910, Dines & Edmunds 1929) or more specifically grey malmstone identified in medieval churches in Chichester (Cordiner & Brook 2017, 42-45) or even Blueheart or Amberley Blue (Cordiner & Brook 2017, 42; 45). The

latter described as a massive pale blue-grey siltstone with a subchonchoidal fracture and used in Storrington Church and Amberley Church in West Sussex and the lower Adur Valley is perhaps the closest match (Cordiner & Brook 2017; 42; 45) to the rather blocky-like bedding seen in the facing of many of these steps. The stone was presumably transported around the coast and up the Thames Estuary to the Tower. The quality of the malmstone is poor, resulting in the step edges being in a degraded, fragmentary condition (**Plate 69**) with individual chunks (50mm across) of stone found detached from the main staircase.

6.2.4 As a result, there has been minor stone step repair/replacement of the outermost paver of the lowest three steps using Ketton stone (Step 1), Reigate stone (Step 2), Caen stone (Step 3) (**Figure 21**; **Plate 65**). The mortar fill behind outermost paver of Step 1 consists of Roman cement, a mortar type patented only after the mid-19th century (Mortar T4), which would provide an indication of the date of these minor repairs (**Figure 22**).

6.2.5 Changes in stone type do occur although these are localised in two areas. First, Steps 21 and 22 consist of a very hard fossiliferous limestone with numerous horseshoe-shaped thick shelled bivalve (possibly oyster) impressions on the surface of the step (**Plate 70**), each 3cm across (**Figure 23**). Detailed investigation shows these may be a lithological variant within the malmstone succession of the Alresford area (Osborne-White 1910, 21) where large fossil concentrations occur within the units of rock. Second, the localised use of white chalk from Steps 32 to 38 (**Figure 25**; **Plate 71**). This chalk lacks the dirtier appearance of French dolomitic chalk or Beer stone from Devon, both of which are found within the primary build of the White Tower (Sanderson 1998, Worssam & Sanderson 1998; Worssam & Sanderson 2008; 305-6). Instead, these chalk blocks may simply have been acquired in the same area as the malmstone, where the chalk lies immediately above the malmstone in the Cretaceous sequence of this part of Surrey/West Sussex.

6.2.6 The two most common medieval freestone types for London, the lime green low-density Reigate stone from the Upper Greensand of Surrey (13 examples; **Figures 21**, **25** and **29**) and the hard, fine yellow Caen stone (1 example; **Figure 21**) from the Middle Jurassic of Normandy are only used sporadically in this section of the Flamsteed steps (**Figure 25**). Further, only one example of Quarr stone, a rock common in the construction of the White Tower is present (**Figure 25**).

6.2.7 Each step usually consists of 4 blocks of stone. The outermost and sometimes the innermost blocks are usually the narrowest (typically 220mm), whilst the blocks in between are wider (typically 450mm) (**Plate 69**). The blocks 'in between' in the lowermost steps (Steps 1 to 12) are particularly narrow (350mm) however above they begin to widen so that by Step 16 and above they can be as much as 640mm across, but typically 550mm (**Figures 21** and **23**). Each step measures between 1.2 and 1.4m across.

6.2.8 There are relatively few tool marks present in these earliest steps (Steps 1 to 12) although occasional narrow diagonal axe markings can be seen on the vertical and plan faces

(**Figures 22** and **24**; **Plate 72**). It seems likely that any axe marks would have been removed or worn away by wear and tear given that malmstone is a relatively soft material, unlike the better quality harder limestone materials that was used just before and after the building break, which has well preserved markings (**Figures 29** and **30**; **Plates 48** and **49**).

6.2.9 The soft fawn very shelly cockle mortar (T1; **Plate 73**) is used in a number of ways in the steps (samples M2 to M5, M7). As well as its conventional use as a bonding mortar (**Plate 74**), it also acts as a sealant or levelling layer beneath (**Plate 75**), on the top of, and along the vertical faces of each paving step. This creates a 10mm thick even, level surface on to which wooden slats or planks would have been placed. Examples of black carbonised wood impressions were occasionally identified lying on the surface of the T1 mortar at Steps 8, 10, 13, 18 (**Figure 24**; **Plate 76**), 33, 36 to 41 and 46 (**Figure 26**) usually on the outer side of the step. In addition, this mortar was also used to fill in the gap behind the small, irregularly shaped malmstone pavers. The best example is the widest step (Step 51; 1070mm across), which has a mortar backing of 720mm (**Figure 28**; **Plate 77**) behind small 350mm malmstone pavers. Occasionally, the mortar also acts as a very narrow 20 to 90mm outermost paver filler as in Steps 32, 34, 42, 48, 50 and 60 (**Figures 26**, **28** and **30**). The mortar fill contains large chunks of Kentish Ragstone rubble (15 to 30mm), occasional malmstone and fragments of reused Roman ceramic building material.

6.2.10 Fragments of Roman flat tile and brick are present as large 30 to 80mm inclusions within the mix of the 1075/79 to 1080 shelly mortar T1 in Steps 15, 16 (Sample CBM2) and 59 (**Figures 24** and **30**). Their appearance in the medieval steps provides an additional body of dating evidence for the 1075/79 to 1100 construction date for the Flamsteed Turret because the earliest medieval ceramic building material for London only begins to be manufactured in the capital after 1135, some 50 years after the completion of the Flamsteed Turret. It follows that only Roman ceramic building material would have been available between 1075/79 and 1100.

6.2.11 From Step 25 upwards there is a subtle change in the inclusion type of this cockle rich mortar used in this fill. Small, red (burnt) flint pebbles (10-25mm across) become more prevalent (see **Appendix 2**) but essentially the mortar ingredients are the same as T1.

Steps 55 to 66: Medieval 1075/79 to 1080 (towards the building break)

6.2.12 Steps 56 to 66 lie just above the Upper Level (Landing 5) and consist of 44 paving slabs (**Figures 3**, **5** and **29**). Although they have the same type of shelly mortar (T1) (**Plate 44**) as that used in Steps 1 to 55, they have their own unique petrological character and quality of carving (**Figures 29** and **30**). This small group of steps has a greater variety of quality freestone types (5) than the lower steps (**Figure 29**). The group lies immediately below the building break in the construction of the White Tower at Step 67 (**Plate 50**) and flush against the wall of the Flamsteed Turret that sees this building break as a change from ashlar to rubble stone (**Plate 51**) (Harris 2008, 36; Fig. 17).

6.2.13 Quarr stone, a hard skeletal featherstone from the northern tip of the Isle of Wight (**Appendix 1**) is the most common type of stone used in this section of the stairwell (18 examples 41%; **Figure 29**). Its presence provides one further chronological indicator for the late 11th century construction date of the Flamsteed Turret as the stone does not continue to have been used widely after the 12th century as the quarries on the Isle of Wight had largely been worked out by this date.

6.2.14 By contrast, the poorer quality malmstone, so prevalent below, only appears in this section sporadically (4 pavers 9%) in Steps 56 and 59 (**Figure 29**; **Plate 78**). Another high quality stone to be used in quantity in this section is the fine hard yellow Caen stone from Normandy (8 pavers 18%) with Steps 60 and 61 made almost entirely of this material (**Figure 29**; **Plates 48** and **49**). Reigate stone (14 pavers 32%) and Chalk (2 pavers 5%) continue to be used (**Figure 29**).

6.2.15 This section of steps is also set apart from the lower steps by their crisp, regular and angular carving (attributed to Norman chisel axe-heads; **Figure 30**). Some of this is attributable to the improved quality of stone types, in particular the Caen stone and Reigate stone, which are ideal freestone materials. Freestone, being a type of limestone or sandstone with a soft open porous texture, enables the rock to be worked or carved in any direction (Leary 1989).

6.2.16 However, this change should also be seen as an overall improvement in the quality of craftsmanship and tools used. Quarr-stone, not the easiest material to work into such regular dimension blocks because it is relatively hard, has been faced very crisply and smoothly in this section. The regular close fitting of these blocks results in very little of T1 mortar being used between the edges of each paving slab or indeed beneath the blocks when seen in cross section (**Figure 30**).

6.2.17 Each block has very narrow regular diagonal tooling marks in elevation, the most clear-cut examples being Steps 60 and 61, which are carved in Caen stone (**Figure 30**). These are axe marks or quarry picks with a cutting edge similar to a point chisel insert (**Plates 48** and **49**). Axes with flat cutting edges can have them aligned with the shaft, like an axe used for cutting wood, or at 90 degrees to it. Axes were traditionally used in Roman carvings in north-west Europe on soft limestone and sandstone a practice that evidently continued with medieval stone cutting, producing a slightly more irregular finish than fine chisel.

6.2.18 Examples of black carbonised wood impressions were especially prevalent in this section of the staircase, lying on the surface of the T1 mortar on Steps 56, 57, 59 and 60 (**Figure 30**). As in other rooms in the White Tower (Harris, 2008, 31) there is widespread use of Quarr stone in the steps towards and immediately below the building break (**Figure 29**). No more conspicuous is this change evident than in the chapel aisles (Harris, 2008. 31; 105-106; figs 74&75) at a similar elevation to this section of the stairs.

6.2.19 This sudden increase in very high quality freestone materials and/or quality workmanship

from Step 56 upwards should be seen in terms of the sudden availability of stone and the best quality masons to embellish the Chapel, where golden yellow Caen, Quarr stone and Reigate stone are all very commonly used at a similar elevation. The availability of these quality stone types for Steps 56 to 66 should therefore be seen as an extension to one of the most important early Norman ecclesiastical building programmes in London.

Steps 67 to 90: Medieval 1090/93 to 1100 (above the building break)

6.2.20 A change in the bedding mortar type from a shelly T1 to a hard, light brown gravel mortar with prominent unburnt chalk inclusions (T2) commences after Step 66 (**Figure 30**). Mortar T2 (Samples M8 to M12) (**Figures 30**, **32** and **34**; **Plates 50**, **67** and **79**) is identical to the same chalk gravel mortar identified elsewhere in the White Tower above the 1080 to 1090/93 building break which begins from a height of approximately 22.7 to 23m aOD (Harris, 2008, 30). Mortar T2 contains no shells.

6.2.21 The building break lies between Steps 66 and 67 (**Figure 30**; **Plate 50**) at an estimated 23.5m aOD height or about one metre (or 5 steps) above the line identified at 22.8m aOD in the surrounding stair wall of the Flamsteed Turret (Harris 2008, 31). The break observed by Harris corresponds with that visible in the wall above Step 58 (**Plate 51**). During this phase of work the break in the wall of the turret was observed to vary between 0.6-1m (22.8 to 24.2m aOD) between Steps 58 to 66 (**Plate 79**). The higher level was found approximate 0.2m above Step 66 and consisted of two courses of ashlar (**Plate 80**).

6.2.22 A total of 34 stone steps (97 paving stones) have this mortar type from Steps 67 to 89 (Upper and Gallery Levels) as well as the Step 90 just above Landing 6 (above Gallery Level) (**Figures 3**, **30**, **32** and **34**). This step forms the uppermost limit of this phase of the timber cover lifting work. In addition, the use of this mortar extends to the bottom four of six steps (G1 to G4) leading from Landing 6 down to the Northern Mural Passage at Gallery Level (**Figures 3**, **5** and **34**).

6.2.23 Two rock types dominate Steps 67 to 89. These are Reigate stone 42 paving slabs (43%) and Quarr stone 30 slabs (31%), which account for over three-quarters of the steps (**Figures 29**, **31** and **33**). This is supplemented by small quantities of Caen stone (13 examples; 13%) and Bembridge Limestone (or Binstead stone), a second rock type from the Isle of Wight (12 examples; 12%). There is a complete absence of malmstone a stone type that constituted upwards of 71% of all the paving blocks below the building break. Bembridge Limestone, a hard fine porcellanous limestone from the easternmost tip of the Isle of Wight characterised by coiled snails of the fossil *Galba* (**Plate 82** and **83**), were only found in large paving slabs of Steps 73 to 77 of the Flamsteed Turret in the Upper Level (**Figure 31**). This rock was not present in the steps below the building break.

6.2.24 Its association with this second (upper) phase of building in the White Tower has also been observed in the construction of St John's Chapel (Harris 2008, 31). Here it only occurs above

the building break for example in 8 of the responds (Harris 2008, 105; Fig. 72).

6.2.25 Like mortar T1, mortar T2 has been used in several ways in the steps. As well as its conventional use as a bonding mortar between the edges of each paving step, it also acts as a sealant or levelling layer beneath, on the top of and along the vertical faces of each paving step. This creates a 10mm thick even, level surface on to which wooden slats or planks would have been placed. Examples of black carbonised wood impressions were rarely identified lying on the surface of the T2 mortar and were observed on Steps 67, 68, 71, 79, 80 and 86 (**Figures 30** and **32**) usually on the outer part of the step.

6.2.26 As with T1, mortar T2 is used to fill in the gaps behind the small paving slabs (this time of Quarr stone, Reigate stone, Bembridge stone and Caen stone). Two excellent examples form two very wide steps. Step 77 (1400mm across) has a mortar backing of 1200mm, behind small 200-240mm Caen stone pavers (**Figures 31** and **32**). Step 89/Landing 6 (1240mm) has 1000mm backing behind small 240mm pavers of Quarr stone (**Figures 33** and **34**; **Plate 85**). On one occasion (Step 74) it acts as a very narrow levelling layer beneath the step (**Plate 84**). As with T1 mortar, mortar fill T2 contains large chunks of Kentish Ragstone rubble (15-30mm), occasional malmstone and fragments of reused Roman ceramic building material. Some Quarr stone rubble was used in the infill of Step 77 (**Figure 32**).

6.2.27 An example of a reused Roman tegulae in the fine sandy Roman fabric *2452* (AD55-160) was present as a 50mm inclusion in Step 80 within the mix of the 1090/93 to 1100 chalky gravel mortar T2 (**Figure 32**). As with T1, its appearance in the medieval steps provide an additional body of dating evidence for a very late (here 1090/93 to 1100) construction date for the Flamsteed Turret. This is because the earliest medieval ceramic building material for London only begins to be manufactured in the capital after 1135, some 30-40 years after the completion of the Flamsteed Turret. It follows that only Roman ceramic building material would have been available during the construction of the Flamsteed Steps.

6.2.28 The continued use of crisply faced and regular tooled step pavers in Caen stone and Reigate stone immediately after the building break in Steps 68, 74 to 76, 78, 80, 81 and 86 (**Figures 31** and **33**) shows that quality craftsmanship and materials were still being used in the Flamsteed Turret after 1093. Not only are the hard blocks of Quarr-stone worked in this way (Step 73), but also one of the hardest limestone types in the British Isles, the condensed fine Bembridge Limestone (Steps 74 and 75; **Plate 84**) was found to have very sharp faced edges. The regular close fitting of these blocks results in very little of T2 mortar used between the edges of each paving slab or indeed beneath the blocks when seen in elevation (**Figures 30** and **32**). The marks on the stones, like the earlier examples, are axe marks or made by quarry picks with a cutting edge similar to a point chisel (**Figures 30** and **32**).

6.2.29 The individual blocks of Quarr stone become much smaller, irregular, and poorly worked towards Steps 89 and 90 (**Figures 31** and **33**). This is shown by the fact that as many as seven blocks of Quarrstone, each measuring between 165mm and 180mm across, were

identified in Step 89 (**Figure 33**; **Plate 85**). This might indicate a reduction in the availability of large Quarrstone blocks and perhaps good masons too.

6.2.30 The continued use of very high-quality freestone materials and/or quality workmanship after the building break from Step 67 upwards to Step 86 (**Figures 29** and **31**) should be seen in terms of a renewed availability of stone and the best quality masons after 1090/93 to complete the construction and embellishment of the Chapel. Very hard Bembridge Limestone, for example, which only appears above the building break in the chapel, is present as very well tooled pavers (Steps 74 and 75; **Figure 31**; **Plate 84**). A downturn in the quality of the block sizes and shapes after Step 86 (**Figures 31** and **33**) may be a result of a cessation in supply of quality stone and craftsmen to the Tower, perhaps following the completion of St John's Chapel.

6.2.31 Very little repair was evident in this section of the steps. Only in Landing 6 (Step 89), adjacent to Steps G1 to G6 leading down to the Northern Mural Passage at Gallery Level, was there some patchwork repair with the inclusion of chunks of late medieval peg tile in fabric *2271* (**Figures 33** and **34**; **Appendix 1**). There was no visible mortar so it was not possible to verify if this was late medieval or reuse of these tiles at a later post-medieval date.

Steps G1 to G6: Medieval Steps Leading Down to the Northern Mural Passage from Landing 6

6.2.32 The bottom four steps (Steps G1 to G4) leading down to the northern mural passage from Landing 6 were found to be pointed in the same hard, light-brown gravel mortar with prominent unburnt chalk inclusions (T2) seen in the Steps 67 to 90 above the building break in the Flamsteed Turret (**Figures 30**, **32** and **34**). This would also indicate that they formed part of the same 1090/93 to 1100 building programme, characteristic of the upper levels of the White Tower above 23m aOD (Harris, 2008, 31).

6.2.33 Rather like the uppermost steps (Steps 89 and 90) of the Flamsteed Turret, they are composed of the same small, poorly worked blocks of Quarrstone (**Figure 33**; **Plate 54** and **86**), each 165-180mm across, which may indicate a downturn in the availability of large stone blocks of this material and perhaps good masons too, possibly following the completion of St John's Chapel.

6.2.34 The uppermost Steps G5 and G6 have undergone wholesale late 19th to early 20th century stone and mortar replacement with minor late 19th to 20th century repairs to Step G1. The uppermost Step G6 consists of a large (1280mm) and relatively shallow (128mm) single machine-made block of York stone (**Figure 33**). This was cemented with a hard, brown flint pebble concrete mortar (Type 5 hereafter T5; see **Appendix 2**) typical of the very late 19th century or more probably 20th century.

6.2.35 Step G5, which had remnants of a wood step, had a foundation containing loose machine-cut, frogged yellow Medway brick in fabric *3035* (**Figure 34**). Although this fabric dates from 1780

to 1940, bricks of this shape and form typically date from 1875 to 1940. Repairs to Step G1 had been pointed in a fine white gritty mortar (T6) comparable with Portland cement, which dates these repairs to no earlier than 1830 (**Figure 34**).

Steps B4 to B19 and Landings 1 to 3: Early 18th century Basement Level stone steps and brick sleeper wall

6.2.36 The Basement Level post-medieval stone steps (B5 to B19) were assessed for suitable replacement stone indents for the worn nosings on the stone of Steps B5 to B7 and B18 to B19 (stone samples S1 to S3) (Hayward 2018). These steps also underwent a detailed stone-by-stone survey.

6.2.37 The 41 stone pavers identified from Steps B5 to B19 (**Figures 19** and **21**) had an entirely different petrological character and form to those used in the higher medieval levels (Steps 1 to 90). All of the stone in Steps B5 to B19 was purpose-made and hand-sawn (**Plate 87**). Steps B5, B6 and B18 each consist of just one stone paver, each 1100-1200mm across. Each of the stone pavers used in Steps B5 to B19 was 400mm deep and roughly 80mm thick requiring no mortar behind the steps and tiny quantities of mortar in the gaps between each paver (**Figures 20** and **22**). The stone steps appear to be part of the realignment of the passageway from that shown on early 18th century plans (**Figures 9** and **10**) to that shown on the 1754 basement plan (**Figure 11**). This change appears to be part of the 1729 to 1753 alterations, presumably to facilitate access to the salt petre stores. A vertical straight joint between the ashlar wall of the medieval stair vice to that of the 1729-53 passage is visible next to Step B16 (**Plate 8**).

6.2.38 Where identifiable, the mortar (T3) forming the foundation of each step consisted of a hard, white shelly mortar containing small snails (gastropods) with scattered coal inclusions (**Figures 20** and **22**; **Appendix 2**). This mortar recipe was used throughout London in the 18th and 19th centuries (Hayward pers. obs.) and is quite different to the bivalve cockle rich shell mortar (T1) associated with the earliest medieval builds of the Flamsteed steps.

6.2.39 The same mortar (T3; Sample M1) was used to point the brick (west) sleeper wall that supports Step B4/Landing 1 (**Figure 20**; **Plate 9**) and the side (south) wall flush against Steps B1 to B4 (**Plates 10** and **11**). The brick wall used to support Step B4/Landing 1 (**Plate 88**) can be dated to the early 18th century based on fabric, bond, form and size. The wall was constructed in English Bond in purple and clinker rich post-Great Fire fabric *3032* (1664-1900) apart from one reused red Tudor/Stuart brick. The bricks are well-made and narrow; typically, 4 inches (100mm) wide and 2 ½ inches (64mm) thick. This wall dates to 1732 to 1734 when brick vaults were inserted in the basement (Harris, 2008, 63).

6.2.40 The stone steps, brick wall supporting Step B4/Landing 1 and adjacent brick wall of the basement were all built in the early 18th century and used mortar T3. The same mortar (Sample M6) was also used to re-point the Reigate stone edge of medieval Step 51/Landing 5

and bond the adjacent York stone pavers (**Figure 28**; **Plate 77**).

6.2.41 Twenty-one polished and machine-cut white/cream Portland stone pavers (see **Appendix 1**) were identified in Steps B8, B10, B12 to B14, B16 to B18 as well as a loose example (stone sample S1) recovered from the area of Step B1 (**Figures 19** and **21**). In addition, Landing 2 was entirely built in Portland stone (**Figure 19**). Portland stone is an exceptionally hard freestone, which only began to be used in London in any quantity after the Great Fire of London and at the Tower of London is widely associated with mid to late 19th century rebuilds and repairs such as those conducted by Anthony Salvin e.g. at the Develin Tower (Hayward & Garwood 2015) and Bell Tower (Hayward 2016).

6.2.42 Two sub-types could be identified (see **Appendix 1**) one much finer and homogeneous consisting of numerous small round calcite grains called ooids known as Portland Whit Bed and quarried extensively for use in London (Hackman 2014). The more common sub-type contained large white oyster shell fragments. Both were quarried from the Upper Jurassic (Portlandian) Beds of the Isle of Portland Dorset. It was suggested that suitable replacement stone from these beds could be used to replace the stone indents for Steps B17 and B18 (**Figure 21**).

6.2.43 Although having a more open porous texture than Purbeck limestone, it can still be a very durable rock, with Class A durability rating (the highest) from Fancy Beach Quarry, Isle of Portland (Leary, 1989, 56). More typically it as a mid-rating of B or C. This and the fact that it is fine grained, homogeneous, available in large blocks and weathers evenly (Leary 1989, 51) makes it highly suitable for exterior, structural work.

6.2.44 Thirteen polished and machine-cut shelly Purbeck limestone pavers (**Appendix 1**) were identified in Steps B5 (sample S2) and B6 (**Plate 89** and **90**), B8 to B12 and B14 to B17 (**Figures 19** and **21**). The widespread quarrying and supply of this dense hard grey flaggy limestone as a paving material, gained momentum from the mid-17th century onwards (Stainer 2000) with slabs being easily shipped around the coast and up the Thames Estuary and then onto to smaller vessels around London. Increased supply and demand continued throughout the 19th century. In the Tower of London, they are used in enormous quantities and are associated with mid to late 19th century rebuilds and repairs such as those conducted by Anthony Salvin e.g. at the Develin Tower (Hayward & Garwood 2015) and Bell Tower (Hayward 2016). Two sub-types were identified (**Appendix 1**) one consisting of small fine Unio shells, the other consisting of large black oyster fragments, known as the Purbeck Grub Bed. Both were quarried from the Lower Cretaceous (Purbeckian) Beds of the Isle of Purbeck, Dorset. It was suggested that suitable replacement stone from these beds could be used to replace stone indents for Steps B5, B6 and B17.

6.2.45 Hopton Wood stone is also a very durable rock, with Class A durability rating (the highest), as well as being shallow bedded and therefore easy to extract (Leary 1989, 60). Five polished and machine-cut pavers were made of Hopton Wood stone or marble (because of its ability to

polish), a light cream crinoidal bioclastic grainstone (Dunham 1962) from the Lower Carboniferous Limestone of Derbyshire (Price 2007). These were identified in Steps B7, B13 (**Plate 91**), B16 and B19 (**Figures 19** and **21**). This stone has been used since the 18th and 19th century to embellish staircases, fireplaces and paving slabs along with similar materials such as Derbyshire Fossil and Petit Granite from the Lower Carboniferous of the Ardennes (Price 2007). It was also identified as railing supports recently at the front of Hampton Court (Hayward 2016). It was suggested that suitable replacement stone from these beds could be used to replace stone indents for Steps B7 and B19 (Sample S3; **Figures 19** and **21**).

6.2.46 Comment needs to be made on a small block of Purbeck marble from the innermost paver from Step B14 (**Figure 21**; **Plates 8** and **92**). Purbeck marble is a condensed, dark grey fossiliferous limestone packed full of small freshwater *Paludina* snails from the Lower Cretaceous of the Isle of Purbeck that is widely used in the Tower of London including medieval lintels and supports. Its identification amongst the early 18th century steps in the basement therefore requires some explanation.

6.2.47 The block of Purbeck marble (**Figure 21**; **Plates 8** and **92**) is located adjacent to what became the base of the inner medieval Reigate stone newel of the Flamsteed Turret in the early 18th century when the passage from the Flamsteed Turret to the basement of the White Tower was altered (compare **Figures 9** and **10** with **11**). Purbeck marble was occasionally reused at the medieval Tower of London from Roman funerary tombs and monumental architecture from the Eastern Cemetery. This block of Purbeck marble was possibly brought in fresh with the early 18th century Purbeck Limestone and Portland stone.

6.2.48 Ceramic building material in the foundation of basement Steps B8 and B13 are post-medieval in appearance (**Figure 22**). Late post-medieval peg tile in the fabric *2276* (1480-1900) was used in the base of Step B8 and early post-medieval Tudor/Stuart red brick in fabric *3047* (1450-1700) reused in the base of step B13 provides another line of supporting material evidence for the early 18th century construction of the basement steps.

7 DISCUSSION AND CONCLUSIONS

7.1.1 The petrological analysis of the Flamsteed steps carried out during the replacement of their timber covers identified the same 1080 to 1090/93 building break as that seen elsewhere in the exterior and interior fabric of the White Tower from 22.7-23.5m aOD (Harris, 2008, 31). The building break, identified by a change from a cockle, shell rich fawn mortar (T1) to a gravel and unburnt chalk hard mortar (T2), was seen in the steps at approximately 23.5m aOD from Step 67 onwards. The break lies at approximately the same height as the change seen in the surrounding turret wall which is shown not only by a change in mortar type but also from ashlar blocks to stone rubble construction (Harris, 2008, 31, fig. 17).

7.1.2 As well as its conventional use as a bonding mortar between the edges of each paving step, T1 mortar, and occasionally T2, was also used as a putty sealant or levelling layer beneath, on the top of and along the vertical faces of each paving step. This created a 10mm thick even, level surface on to which wooden slats or planks would have been placed. Examples of black carbonised wood impressions were occasionally identified lying on the surface of the T1 mortar and T2 mortar usually on the outer part of the step.

7.1.3 Detailed petrological recording was also successful in identifying malmstone as the principal paving step stone-type associated with the medieval build, represented by 179 examples of (48%) out of all the 371 stone pavers from this section. Above the building break, however it was not used at all. This material type had not been identified in the White Tower before now (Sanderson 1998; Worssam & Sanderson 1998; Worssam & Sanderson 2008, 305-306), although it is possible that it has been mistaken for the lithologically comparable Reigate stone from the same stratigraphic horizon, but from south-west Surrey not north-east Surrey.

7.1.4 A sample of the stone (S4; **Figure 21**) found it to be lithologically comparable with samples of worked malmstone retained from excavations at the medieval Leper Hospital of St Mary Magdalen near Winchester (Hayward pers. obs.). Malmstone is used extensively elsewhere in Winchester in 14th century rebuilds to Winchester Cathedral (Tatton-Brown 1992, 37-46), the 1222 Winchester Castle and Winchester College (Tatton-Brown 1992, 37-46). Slightly closer, it has been used in medieval construction projects at Farnham Church and Farnham Castle (Sowan 1975).

7.1.5 This stone a poor-quality, light-cream grey muddy micaceous limestone. It had a good match with a sub-type Grey Malmstone described as a massive, grey to green grey siltstone and used extensively in the medieval churches of the Chichester area and the lower Adur Valley (Cordiner & Brook, 2017, 42; 45). In terms of maritime accessibility, it would have been economically viable to transport stone around the coast and up the Thames Estuary to the Tower.

7.1.6 Another key petrological find was the identification of a great deal of easily worked Caen stone, Reigate stone and especially Quarr stone from the Isle of Wight, approaching the

building break between steps 56 and 66. These all displayed crisp axe carving suggesting an influx of better quality materials and artisans at this juncture. This find is in keeping with other rooms of the White Tower (Harris, 2008, 31), where Quarr stone is used extensively immediately below the building break. No more conspicuous was this change evident than in the chapel aisles (Harris, 2008. 31; 105-106; figs 74&75) at a similar elevation to this section of the stair.

7.1.7 Accounting for the sudden increase in very high quality freestone materials and/or quality workmanship from Step 56 upwards should be seen in terms of the sudden availability of stone and the best quality masons to embellish the Chapel, where golden yellow Caen, Quarr and Reigate are all very commonly used at a similar elevation. The availability of these quality stone types for Steps 56 to 66, should therefore be seen as an extension to one of the most important early Norman ecclesiastical building programmes in London.

7.1.8 Further petrological discoveries included the localised use (Steps 72 to 75), above the building break of the very condensed Bembridge Limestone, also from the Isle of Wight. This, one of the hardest limestone materials in the British Isles, had also been crisply axed carved. Its presence in the late 11th century steps should be seen in terms of a resurgence in the building material and quality workmanship associated with St John's Chapel, following the building break. It is only above the building break that this limestone is being used in St John's Chapel (Harris 2008, 105-106, figs 74&75).

7.1.9 Above the building break, Reigate stone becomes the most common rock type, with the continued widespread use of the Quarr stone. Quarr stone is a good chronological indicator for 11th century building, as after this date supplies of stone from outcrop in the northern part of the Isle of Wight largely run out.

7.1.10 An equally useful chronological indicator was the occurrence of just Roman ceramic building material in both mortar types associated with the late 11th century build. Its appearance in the medieval steps provide an additional body of dating evidence for a very late (1075/79 to 1100) construction date for the Flamsteed Turret. This is because the earliest medieval ceramic building material for London only begins to be manufactured in the capital after 1135, some 30-40 years after the completion of the Flamsteed Turret. It follows that only Roman ceramic building material would have been available during the construction of the Flamsteed Steps.

7.1.11 The bottom four steps (G1-G4) leading down from Landing 6 to the northern mural passage at Gallery Level have retained their medieval fabric. Like the adjacent uppermost steps (Steps 85 to 90) they are made of poor quality Quarr stone and Type 2 mortar, so both sets of steps are contemporary 1090/93-1100 builds.

7.1.12 Late post-medieval repairs have taken place to Steps G1 to G6 including the wholesale replacement of Step G6 with a complete machine-made York stone paver. Post-medieval repairs to the medieval stone steps of Flamsteed Turret are rare and sporadic at best. There

are occasional patchwork repairs of individual steps, such as Steps 1 to 3.

7.1.13 The Basement Level steps (Steps B5 to B19) of the Flamsteed Turret are early 18th century in date. The brick wall supporting Step B4/Landing 1 was built of narrow, well-made post-Great Fire bricks pointed in a hard, gastropod shell mortar (T3) and dates to 1732-1734 when brick vaults were inserted in the basement.

7.1.14 Above Step B4/Landing 1, Steps B5 to B19 are made of high quality cut paving blocks of polished Portland stone, Purbeck limestone and Hopton Wood marble all common late post-medieval (1700-1900) paving stone types. These appear to have been laid 1729 to 1753 when the passage from the Flamsteed Turret to the basement of the White Tower was rearranged (compare **Figures 9** and **10** with **11**).

7.1.15 The historic building recording and watching brief during the replacement of the timber treads established that older timber covers still exist over Steps 90 to 106. A previous watching brief (Phase 1) carried out in December 2016 established that timber inserts had been hammered into the mortar of the medieval treads and timber planks were fixed to these inserts with late 18th/early 19th century rose-headed nails. The timber covers were secured to these planks. Torn pieces of newspaper under one of the steps suggest that they were lifted in 1938.

7.1.16 Although timber inserts were found in the medieval mortar of the stair vice from Steps 1 to 89 these were not used by the timber covers that were in place at the start of the project. These timber covers were late 20th century in appearance with steel nosings housing grit treads. The planks of wood had been glued tighter and secured with cross head screws. Faint graffiti on one of the timber treads of '1971' may suggest the date that they replaced the earlier scheme. Graffiti on Step 14 shows that it was lifted on 04/04/1991. Datable finds under the covers included a 1960 shilling, 1995 and 2001 tickets to the Tower of London and a 2007 Tower of London tourist leaflet.

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APPENDIX 1: STONE, BRICK AND TILE TYPES

Introduction

The twenty building material fabrics recorded from the Flamsteed Steps can be subdivided further into fourteen rock types and six ceramic building material fabrics. Each stone-type is described, sourced and discussed below by frequency starting with the medieval (late 11th century) paving stone types, followed by the construction of the early 18th century stone basement steps and the stone types associated with the Victorian step repairs.

This fabric review includes an identification of ceramic building material used within the steps and as inclusions within the medieval mortar.

Primary late 11th century paving stone types

Malmstone

The most startling discovery from this petrological review of the Flamsteed Turret steps was the use of a huge quantity (179 pavers) of a poor-quality, light-cream, grey muddy micaceous limestone (malmstone). It is only used in primary phase of construction, associated with T1 cockle rich mortar. Although approaching 50% of all the stone from the late 11th century steps that were recorded, in the primary phase it accounts for 71% of all stone. Indeed, up to Step 35 it is the main stone type to be used (**Figures 21**, **23** and **25**) and after Step 59 ceases to be used at all (**Figures 29**, **31** and **33**).

In detail, it fizzes readily when dilute hydrochloric acid is added, confirming that it is calcareous in composition. It has a grey-green tinge when moist and has blocky-like bedding and is completely non-fossiliferous.

There is an excellent match with samples of worked malmstone retained from excavations at the medieval Leper Hospital of St Mary Magdalen near Winchester (Hayward pers. obs.). Malmstone is used extensively elsewhere in Winchester in 14th century rebuilds to Winchester Cathedral (Tatton-Brown 1992, 37-46), the 1222 Winchester Castle and Winchester College (*ibid.*). Slightly closer, it has been used in medieval construction projects at Farnham Church and Farnham Castle (Sowan 1975).

The principal outcrop of malmstone (Upper Greensand Formation), Selbourne Group is at Alresford, Selborne and Farnham of East Surrey (Osborne-White 1910; 16; 21-26; Dines & Edmunds 1929, 40; Cordiner & Brook, 2017, 42-45). Although variable in character certain outcrops described from the Alresford area provide an excellent match with the material used in the stairs; thus *"a soft marly, micaceous, grey malmstone with some glauconite passing down into harder, blocky or massive grey malmstone – partly calcareous, partly purely siliceous"* Osborne-White 1910, 16).

Recent work (Cordiner & Brook, 2017, 42-45), would indicate that a sub-type Grey Malmstone described as a massive, grey to green grey siltstone and used extensively in the medieval churches of the Chichester area and the lower Adur Valley is the closest match. In terms of maritime accessibility, it would be economically viable to transport stone around the coast and up the Thames

Estuary to the Tower.

Another sub-type somewhat resembles the stair material, is Blueheart or Amberley Blue a massive pale blue-grey siltstone with sub-chonchoidal fracture (Cordiner & Brook, 2017, 42; 45) as used in Storrington and Amberley Church walls in West Sussex.

Reigate stone, from the same geological horizon but from north Surrey and used extensively in the White Tower including the upper courses of the Flamsteed steps (see below) (Harris, 2008, 42; 105-106; Figs 73-74; Sanderson 1998; Worssam & Sanderson 1998) differs in the following ways. First, Reigate stone when weathered or slightly worn spalls in very thin sheets, whereas the Malmstone is more blocky and robust and tends to fall off in small blocky chunks. Second, when examined close up using a hand lens and especially a small portable microscope and laptop (Martin Michette pers. obs.), the malmstone lacks the more open green (glauconitic) and micaceous texture of Reigate stone.

Material type	Number and Proportion in surviving primary steps	Use in Flamsteed Steps	Whereabouts
Malmstone	Number=179 48.9%	Primary late 11th century paving stone material	The most common stone step type associated only with steps from the primary phase of construction before the 1080 building break Steps 1 to 34, 37 to 56 and 59 (**Figures 21**, **23**, **25**, **27** and **29**).

Reigate stone (fine glauconitic calcareous siltstone)

This low-density, poorly cemented micaceous greensand exploited from the Upper Greensand quarries of Reigate-Mertsham has survived in a very good state of preservation in parts of the Flamsteed steps. Indeed, after malmstone, it is the second most common freestone paving material, accounting for a fifth of the all the paving slabs. As with many of the other lithotypes (Caen stone, Quarr stone) it only really starts to be used towards and immediately after the building break, where it becomes the predominant paving material.

Normally, because of its susceptibility to external weathering and pollution the Reigate stone fabric would have long since spalled and decayed and been replaced by post-medieval freestone materials. However, with no diurnal and annual temperature range in this sealed environment these internal steps have survived largely intact for approaching 1000 years, albeit with minor spalling. Medieval mortar sealant and wooden step cover would have ensured that pollutants would not have penetrated the fabric. Furthermore, these covers would have also protected the normally structurally unsound, low density porous (30%) (Sowan 2000, 145) Reigate fabric from heavy loading including footfalls.

Material type	Proportion	Use in Flamsteed Steps	Whereabouts
Reigate stone	Number=70 19.1%	Primary late 11th century paving stone material	The second most common late 11th century paving step material of the Flamsteed Steps – before the 1080 building break. Steps 2, 35, 36, 39, 40, 42, 43, 46, 47, 52, 53, 55 to 59, 61 and 66 (**Figures 21**, **25** and **29**). After the 1080 to 1090/93 building break Steps 67 to 72, 76, 78 to 84 (**Figures 29** and **31**).

Quarr-stone (white skeletal grainstone)

A good indicator of early medieval quarrying, this hard-skeletal limestone or "featherbed" quarried from the (Oligocene) of the northern tip of the Isle of Wight coast does not continue to have been used after the 12th century as the quality stone had been quarried from the quarries on the Isle of Wight.

It use in the 1075/79 to 1100 Flamsteed Turret steps, as the third most frequent lithotype reinforces this chronological link. The steps made from this rock and crisply carved by masons were identified immediately before and after the building break, something that is seen in the Chapel (Harris, 2008, 42; 105-106; figs 73&74; Sanderson 1998; Worssam & Sanderson 1998), where Quarr and other high quality stones suddenly become available in some quantity.

Material type	Proportion	Use in Flamsteed Steps	Whereabouts
Quarr stone	Number=63 17.2%	Primary late 11th century paving stone material	The third most common late 11th century paving step material used in the Flamsteed Steps, especially towards and after 1080 building break. Before building break Steps 37, 62 to 65 (**Figures 25** and **29**). After the 1080 to 1090/93 building break in Steps 69, 72, 73, 85 to 90; Gallery steps G1-G4 (**Figures 29**, **31** and **33**).

Caen stone (yellow packstone)

There was a good match between stone steps made from a condensed, pale-yellow to pale-orange fine-grained pelletal packstone (Dunham 1962) and Caen stone or Calcaires de Caen limestone from the Middle Jurassic (Bathonian) of Normandy. This fine durable high-quality limestone is used in some quantity in the White Tower most notably the piers and arches of the Chapel (Harris, 2008, 105-106; figs 73&74) and especially above the building break. Their use mainly (though not exclusively) in the steps towards and above the building break in the Flamsteed Turret, therefore concurs with the evidence from the White Tower as a whole.

It is interesting to note that an upsurge in the use of Caen stone, Quarr stone and Bembridge stone in the Flamsteed Turret towards and immediately above the 1080 to 10930/93 building break coincides with the use of this high quality stones in some quantity for the embellishment of the Chapel, immediately before and after the building break. (Harris 2008, 105-106; figs 73&74). This cannot merely be a coincidence. Rather a sudden availability of quality stone and with it the best stone workers. Indeed, the stone steps made from Quarr and Caen stone from this area are those that are most crisply and intricately carved.

This is a rock type that forms part of the package of freestone types (Purbeck marble, Reigate stone, Taynton stone) used in major medieval ecclesiastical (Hayward in prep.; Samuel 2011; Blows & Worssam 2011) and defensive (Worssam & Sanderson 1998; Harris 2008) projects in London.

Material type	Proportion	Use in Flamsteed Steps	Whereabouts
Caen stone	Number=22 6%	Primary late 11th century paving stone material	Occasional use as a 11th century paving step material especially towards and after the 1080 to 1090/93 building break Before the 1080 building break in Steps 3, 56, 60 to 62 (**Figures 21** and **29**). After the 1080 to 1090/93 building break in Steps 69, 76 to 78, 84 to 86 and 88 (**Figures 29**, **31** and **33**).

Chalk

Examples of finely cut, soft white chalk from the Upper Cretaceous of the Thames Valley were worked into steps in a restrictive area of the earlier 1075/79 to 1080 build, especially Steps 32 to 38 (**Figure 25**). Here they are used in conjunction with the Malmstone and Reigate stone and bonded in the cockle rich T1 Mortar. They lack the "dirtier" appearance of the French dolomitic chalk or Beer stone chalk rock from Devon, both of which contain fragments of echinoid fossils and are present within the early primary fabric of the White Tower (Sanderson 1998; Worssam & Sanderson 1998; Worssam & Sanderson 2008, 305-306).

Material type	Proportion	Use in Flamsteed Steps	Whereabouts
Chalk	Number=13 3.6%	Primary late 11th century paving stone material.	Occasional use as a 11th century paving step material in a small area only before the 1080 building break Steps 32 to 38, 44, 59 and 60 (**Figures 25** and **29**).

Bembridge Limestone (Binstead stone)

This stone is used in a very restrictive area of the Flamsteed steps, specifically Steps 74 to 77 above the 1080 to 1090/93 building break (**Figure 31**). It has an identical match with Bembridge Limestone from the Tertiary (Oligocene) of the north-eastern coast of the Isle of Wight. This very hard concretionary pale cream limestone with the distinctive large coiled gastropod *Galba* is ideally suited to withstand extensive wear experienced by footfall (see also (Worssam & Sanderson 1998).

It is interesting to note that its use in the Tower of London is restricted to the White Tower, specifically in the vicinity or just above the building break in its south elevation and in the Chapel, where it is found pointed in the same later T2 chalk mortar as the Flamsteed Steps (Harris 2008, 31; 105; figs 73&74).

Material type	Proportion	Use in Flamsteed Steps	Whereabouts
Bembridge Limestone	Number=12 3.3%	Primary late 11th century paving stone material	Occasional use as a 11th century paving step material in a small area only after 1080 to 1090/93 building break in Steps 74 to 77 (**Figure 31**). Associated with mortar T2 only.

Unidentified shelly limestone

From Steps 20 and 21 associated with the primary 1075/79 to 1080 Flamsteed steps was a pale cream grey limestone dominated by large hollowed out (5cm) curved oyster shells or bivalve fragments (**Figure 23**). Although this may be a lithological variant of the ubiquitous malmstone, which sometimes contains the large bivalve *Inoceramus concentriculs*, *Plagiostroma Gibbosa*, such as those found within the thick, (24-60 metre) malmstone sequence of the Alresford area (Osborne-White 1910, 21), there was no exact match.

Although the very durable fossil rich Thanet sandstone from the Tertiary of North Kent is found within the 1075/79 to 1080 fabric of the White Tower this should be excluded as a candidate material. These only occur as unyielding dogger blocks and the associated *Artica* fossils are quite different to these examples from the Flamsteed Turret.

Material type	Proportion	Use in Flamsteed Steps	Whereabouts
Unidentified shelly limestone	Number =5 1.4%	Primary late 11th century paving stone material	Rare localised use as a 11th century paving step material in a small area before the 1080 building break in Steps 20 and 21 (**Figure 23**).

Post-medieval paving stone types (Basement Level Steps B5 to B19) and replacement stone in Steps G1 to G6 from the Flamsteed Turret to Gallery Level

Introduction

Characteristic of the steps at Basement Level and above are a group of very hard limestone types that easily polish due to extensive and prolonged foot tread and that were very popular flagstone and paving stone materials during the 18th and 19th centuries. Some (Steps B5 to B7, B17 to B19; **Figures 19** and **21**) had worn or broken away necessitating preliminary hand specimen identification and subsequent sampling (Hayward 2018).

Portland stone 21 examples 51.2% of all stone

Portland stone Whit Bed (fine grain prominent white oolite)

Present as complete and fragmentary paving slabs; Portland Whit Bed is a hard, light grey coloured open textured durable limestone. It can be classified as a freestone that is a limestone with a soft open porous texture that enables the rock to be worked or carved in any direction, yet still be hard enough to withstand external weathering for use as paving slabs (Leary 1989; Stainer 2000, Sutherland 2003).

In hand specimen, it is dominated by very small (<0.5mm) round white carbonate grains called ooids with occasional high oyster content, as shown by harder, sparry elongated flecks of re-crystallised shell that can withstand weathering. Its homogeneity provides a flat even surface.

An exact match was possible with a type of Portland stone known as the Whit Bed (Leary 1989, 51), which has a comparable very pale grey fine open oolitic texture with flecks of oyster, possibly *Trigonia*. The widespread use of Portland stone in London from the mid-17th century onwards (Hackman 2014) and especially the 19th century is well documented. Much of the late 19th century ashlar and crenellated repairs to the Tower by Anthony Salvin were made from this stone. It develops a distinctive sheen when used as a stepping stone.

Although having a more open porous texture than Purbeck limestone, it can still be a very durable rock, with Class A durability rating (the highest) from Fancy Beach Quarry, Isle of Portland (Leary, 1989, 56). More typically it is a mid-rating of B or C. This and the fact that it is fine grained, homogeneous, available in large blocks and weathers evenly (Leary 1989, 51) makes it highly suitable for exterior, structural work.

Material type	Proportion	Use in Flamsteed Steps	Whereabouts
Portland stone (Whit Bed)	Number=10 24.4%	Early 18th century paving material	Basement Area only Step B7/Landing 2, B8, B13, B16 to B18 (**Figures 19** and **21**).

Portland stone Oyster Rich (grain prominent white oolite)

An oyster rich sub-type of Portland stone consisting of very large (up to 10cm) fragmentary thick grey *Ostrea* fragments was identified in some quantity from Landing 2/Step B7. These were probably quarried from the Whit Bed but from another outcrop of the Isle of Portland.

Material type	Proportion	Use in Flamsteed Steps	Whereabouts
Portland stone (oyster rich)	Number=11 26.8%	Early 18th century paving material	Basement Area only Landing 2/Step B7, B10, B12 and B14 (**Figures 19** and **21**).

Purbeck Limestone 13 examples

The other common paving stone material type to be used in the Basement steps were two different types of dark grey shell rich calcareous mudstones, collectively Purbeck limestone quarried from different horizons of the Lower Cretaceous of the Isle of Purbeck. Elsewhere in the Tower of London (Palmer & Shaffrey 2011, 14; Hayward & Garwood 2015; Hayward 2016; 2017b) these hard slabby stones are associated with late post-medieval building phases and were used in London widely from the late 17th century onwards.

This stone type is present as complete paving slabs up to 1m in length e.g. in Steps B5 and B6 and part of B17 (**Figures 19** and **21**). These dense hard dark grey flaggy limestones are characterised to a greater or lesser extent on the bedding surface by the outline of small complete or near complete sometimes black, bivalves, identified as the genus *Unio*. The examples from the aforementioned paving slabs have a light grey hue with small white *Unio*. unlike the paving slab from Step B11 which has numerous dark grey bivalves, characteristic of the Purbeck Grub Bed. However, the fact that they are made of the same fossils suggests that they are from broadly similar geological horizons.

An exact match was possible with Purbeck Limestone, a hard-Lower Cretaceous fossil rich marine calcareous mudstone from the Dorset coast centred on the Isle of Purbeck at places such as St Aldhelm's Head, Langton Matravers and Swanage. This rock is quarried today as ornamental stone but has in the past been an important source of roofing material (Roman) and then in the early post-medieval period as an ornamental paving stone often associated with gardens. A case in point were the large quantity of Purbeck limestone pavers identified from the mid-17th century Montagu House excavations in West London (Hayward 2017c, 157). The widespread quarrying and supply of this stone as a paving material, gained momentum from the mid-17th century onward (Stainer 2000). Slabs were easily shipped around the coast and up the Thames Estuary and then onto to smaller vessels around London. Increased supply and demand continued throughout the 18th and 19th centuries.

As well as being shallow bedded and therefore easy to extract (Leary 1989 60) it is a very durable rock, with Class A durability rating (the highest).

Purbeck Limestone Fine Corbula sub-type

Material type	Proportion	Use in Flamsteed Steps	Whereabouts
Purbeck Limestone (standard Corbula sub-type)	Number =9 22%	Early 18th century Basement steps	Basement Area only B5, B6, B8 to B10; B12; B16 and B17 (**Figures 19** and **21**)

Purbeck Limestone Black oyster sub-type

Material type	Proportion	Use in Flamsteed Steps	Whereabouts
Purbeck Limestone (black oyster Grub sub-type)	Number =4 9.8%	Early 18th century Basement Steps	Basement Area only Steps B11, B14 and B15 (**Figure 21**)

Hopton Wood Stone

Light-cream crinoidal bioclastic grainstone (Dunham 1962).

Few examples including two steps requiring repair (Steps B7/Landing 2 and B19/Landing 3) were made from a third condensed limestone type. Somewhat comparable in colour to the lighter Portland Whit Bed, this limestone is made from circular crinoid stem sections rather than oysters. The whiter crinoid stems, and fragments are set within a fine condensed beige matrix. Crinoids or sea lilies are a common fossil from older Carboniferous limestones rather than younger Jurassic limestones. This would indicate the rock is from a very different part of the British Isles. For example, South Wales, Forest of Dean, Bristol and the South Pennines, however, Carboniferous Limestones also outcrop in the Belgium area.

Lower Carboniferous Limestone Derbyshire (Hopton Wood Marble; Derbyshire Fossil) or Belgium (Petit Granite)

Various high quality condensed crinoidal limestones from the Lower Carboniferous of the British Isles have been used since the 18th and 19th century to embellish staircases, fireplaces and paving slabs including Derbyshire Fossil and Hopton Wood Marble or Stone (Price 2007). The closest match is Hopton Wood stone or marble (so-called because of its ability to polish).

Material type	Proportion	Use in Flamsteed Steps	Whereabouts
Hopton Wood stone	Number =5 12.2%	Early 18th century Basement Steps	Basement Area only Steps B7, B13, B16 and B19 (**Figures 19** and **21**).

Purbeck Marble (gastropod rich packstone)

Although Purbeck Marble comes from the same geological formation as Purbeck Limestone, it needs to be considered separately. This is because this hard, light-grey condensed fossil rich limestone dominated by the small 10mm freshwater gastropod *Paludina carinifera* was extensively used in medieval London (Hayward in prep.; Samuel 2011) and especially the Tower of London. Its density

and durability (when used for interior work and not exposed to chemical weathering) made it ideally suited as a lintel material for example in the interior of the Upper Chamber of the 1190 Bell Tower (Hayward, 2016). The sole example here identified from the innermost paving slab of Step B14 is thought to date to the early 18th century when the passage from the Flamsteed Turret to the basement of the White tower was rearranged (compare **Figures 9** and **10** with **11**). Although it appears to support the much lower density Reigate stone curving newel of the 1075/79 to 1080 primary build of the Flamsteed Steps, it is thought more likely to be early 18th century rather than medieval in this context.

Material type	Proportion	Use in Flamsteed Steps	Whereabouts
Purbeck Marble	Number =1 0.3%	Early 18th century paving slab	One example forms the innermost paving slab of Step B14. Although it also appears to support the base of the newel of the 1075/79 to 1080 staircase, it is thought more likely to be early 18th century rather than medieval in this context.

Ketton stone

A small replacement block of Ketton stone, a prominent honey coloured oolitic limestone quarried from the Middle Jurassic (Bajocian) of Rutland was identified as the outermost block of Step 1 (**Figure 21**). This is almost certainly a small late 19th /early 20th century repair because the stone is so widely used throughout the Tower of London as a replacement stone for example in the Bell Tower at this date (Hayward 2016). Some grey gravel mortar with small brown flint pebbles (T7), only widely used from in the late 19th/early 20th century, was located on this step (**Figure 22**).

Material type	Proportion	Use in Flamsteed Steps	Whereabouts
Ketton stone	1 example (0.3%)	Post-medieval stone replacement in step	Step 1 repair only (**Figure 22**)

York stone

The availability of this hard laminated olive green micaceous flagstone from the Upper Carboniferous (Elland Flags) of Yorkshire as paving material only became widespread from the mid-19th century onwards in London with the development of the railway network. The stone was used as one complete block 128mm thick and 1280mm long for Step G6 at the entrance from the Flamsteed Turret to Gallery Level. It was machine-sawn with prominent linear tool marks on its vertical face and bonded in a conglomeratic pebble concrete (mortar T5), which would date it from the late 19th to early-mid 20th

century (**Figure 34**).

York stone pavers were located adjacent to the Flamsteed stairwell in the entranceway at Step 51 from the Upper Level. These were pointed in the same hard, white gastropod rich shell and coal speckled mortar (T3) seen in the construction of the early 18th century basement steps (Steps B1 to B19) and brick sleeper wall. Its association here with York stone is more likely to represent a mid-late 19th century date.

Material type	Proportion	Use in Flamsteed Steps	Whereabouts
York stone	1 example 0.3%	Post-medieval replacement Paver	Step G6 entrance from the Flamsteed Turret to Gallery Level bonded in conglomeratic pebble concrete (late 19th to early-mid 20th century) Mortar T5 (**Figure 34**). Also seen as replacement paving stone from the Upper Level into the Flamsteed Turret at Step 51 associated with Mortar T3.

Ceramic Building Materials

Brick wall supporting Landing 1/Step B4

The twelve-course brick wall supporting Landing 1/Step B4 can be dated to the early 18th century based on bond, fabric, quality of brick and associated mortar. It is in English Bond (alternate stretcher courses and header courses). The brick, with the exception of one reused red Tudor/Stuart brick, is in the purple and clinker rich post-Great Fire fabric *3032* (1664-1900). The bricks are well made, and narrow typically 4 inches (100mm) wide and thick 2 ½ inches (64mm). The mortar is a hard white lime mortar (T3) with small gastropod (snail) shells and flecks of clinker. Combined, these features suggest that the brick support and adjoining sidewalls date to the early 18th century.

Material type	Use in Flamsteed Steps	Whereabouts
Post-Great Fire brick. Narrow sharp arises Fabric *3032* 1666-1900	Brick sleeper wall support for Landing 1/Step B4 and side wall	12 course wall supporting Step B4 Associated with shelly (snail) Mortar T3

Medieval Rubble Core Materials and Mortar Inclusions

Kentish Ragstone sensu strict

This especially, hard compact, cherty and light-grey sandy limestone was used as an ingredient (as 5-10cm rubble fragments) in both shelly mortar T1 and chalk rich mortar T2 in Steps 1 to 90 of the Flamsteed Turret. The stone quarried from the Lower Greensand (Hythe Beds) of Kent, especially

Maidstone is of a type used extensively by the Romans for the construction of the London City Wall as well as the rubble-stone and rough-facing ashlar of the medieval Tower of London including the earliest masonry in the White Tower (Worssam & Sanderson 2008).

Kentish Ragstone was also identified as a post-medieval foundation rubble beneath basement Steps B5 and B6. This is not surprising as this is by far the most common material type to be used in the Tower as a whole (all periods) for example Wardrobe Tower (Hayward 2017b), Develin Tower (Hayward & Garwood 2015); Devereux Tower (Palmer & Shaffrey 2011), Bell Tower (Hayward 2016), Well Tower (Hayward 2017a) and the White Tower (Worssam & Sanderson 2008).

Material type	Use in Flamsteed Steps	Whereabouts
Kentish Ragstone (hard sometimes cherty)	Inclusion in late 11th century medieval mortar types T1 and T2 Rubble foundation	Steps 1 to 90 Basement Steps B5 and B6

Roman Brick and Tile

Roman *tegulae* (with its distinctive flange), flat tile and brick are present as large 30-80mm inclusions within the mix of both the 1075/79 to 1080 shelly mortar T1 (Steps 15, 16 and 59; **Figures 24** and **30**) and chalk inclusion rich T2 mortar after the building break of 1080 (Step 80; **Figure 32**). These provide an additional body of dating evidence for the 1090/93 to 1100 construction date for the Flamsteed Turret. This is because the earliest medieval ceramic building material for London only begins to be manufactured in the capital after 1135[1], some 50 years after the completion of the Flamsteed Turret. It follows that only Roman ceramic building material would have been available between 1075/79 and 1100.

The material is all in the very common fine London red sandy brick-earth fabric*2452*[2] (AD55-160). This could have come from a dismantled section of the town wall lacing courses or Roman residential buildings close to the White Tower (Parnell 1982) or later Riverside Wall.

Material type	Use in Flamsteed Steps	Whereabouts
Fabric *2452* (Fine red sandy fabric) AD55-160	Reused in late 11th century medieval mortar T1 and T2	Before 1080 building break in Steps 15, 16 and 59 (Brick and Tile) **(Figures 24** and **30)** After 1080 to 1090/93 building break in Step 80 (Tegula) **(Figure 32)**

[1] With very coarse sandy shouldered peg tile fabric *2273* Museum of London Fabric Series
[2] Museum of London Fabric Series

Post-Medieval Ceramic Building Rubble infill materials

A small group of fragmentary post-medieval brick and peg tile fabrics, reused as foundation material for later repairs or the builds for the Basement Level, are included here as they provide valuable dating evidence for the Flamsteed Steps.

Tudor brick

As well as a reused whole red Tudor/Stuart brick in the brick wall support for Landing 1/Step B4, another reused example was found in the foundation of the early 18th century basement Step B13. Bricks in this red sandy fabric *3046* were manufactured in London brickearth between AD1450-1700. They were used throughout the Tower, especially for fireplace surrounds and chimney flues. This particular example could have come from the White Tower or from one of the adjoining Towers. The adjacent Wardrobe Tower, partly demolished in the 1880s has for example remnant flues made from this brick fabric that are visible today (Hayward 2017b).

Material type	Use in Flamsteed Steps	Whereabouts
Tudor Red brick fabric *3046*	Rubble core foundation post-medieval basement steps	1 example foundation rubble Step B13

Yellow Medway Stock Brick

Extensive repair work to Gallery Steps G1 to G6 include very late 19th to 20th century alterations, especially to Steps G5 and G6. Part of a machine frogged yellow Medway brick in fabric *3035* has been used in the Step G5 can be dated to the late 19th/early 20th century (**Figure 33**).

Material type	Use in Flamsteed Steps	Whereabouts
Yellow London stock frogged brick in fabric *3035* 1850-1940	Replacement Rubble core foundation	Step G5 leading from Gallery Level to the Flamsteed Turret (**Figure 33**)

Late medieval to early post-medieval peg tile

Limited to a small area of repair on the uppermost surface of Landing 6/Step 89, perhaps to level off an uneven floor surface caused by footwear and damage are a small group of broken peg tiles in fabric *2271* (**Figure**s **33** and **34**). These have a characteristic black reduced core. As peg tiles in this fabric only begin to be manufactured after 1180, they can only have been added at least 100 years after the construction of the Flamsteed Turret. Moreover, they lack the characteristic glaze, thin depth and uneven texture of the earliest periods of manufacture (1180-1450) and are instead more probably

very late medieval to 1800 repairs. No associated mortar was recovered.

Material type	Use in Flamsteed Steps	Whereabouts
Late medieval to early post-medieval peg tile fabric *2271* 1400-1700	Repair rubble core ingredient	Step 89 (**Figures 33** and **34**)

Post-medieval peg tile

Examples of unglazed post-medieval red sandy fabric *2276* peg tile with a fine moulding sand (1700-1900) were present in the foundation of two early 18th century steps (Steps B8 and B18) at Basement Level. They probably acted as localised levelling or coursing (lacing).

Material type	Use in Flamsteed Steps	Whereabouts
Post-medieval peg tile fabric *2276* fine moulding sand 1700-1900	Rubble core foundation post-medieval basement steps	Step B8 and B18

APPENDIX 2: Mortar types

Mortar Type	Description	Use in the Flamsteed Steps
T1	**Soft crushed bivalve shell rich lime mortar** Soft sometimes cream-fawn lime biscuity mortar with numerous complete 20-30mm cockle shells and crushed shelly debris Poorer quality mix used in large area behind irregular steps with Kentish Ragstone, grey, sometimes red pebble flint (Steps 25 to 66) up to 25mm across and grey malmstone fragments Occasional reused Roman tile and brick 30-80mm across	1075/79 to 1080+ Steps 1 to 66 (**Figures 22**, **24**, **26**, **28** and **30**): It is used as bedding mortar between joints of each block and found as a sealant up to 10mm thick covering the steps and the step edges. This ensures a flat regular impermeable surface covering the irregular shaped blocky malmstone which occurs in Steps 1 to 59 and is only associated with this mortar type. The poorer quality mix appears at the back of each step. It sometimes acts as a substitute stone material completely filing gaps at the very outermost 5-10cm of Steps 32, 34, 42, 48 and 50. Same as Type 1 shelly mortar with concentrated bivalve shells (Harris 2008, 30) used in the initial construction of the external elevations up to 22.7m to 23.5m aOD (Harris 2008, 30), which marks the construction break of the White Tower - indicating Steps 1 to 66 are associated with the earliest (1075/79 to 1080) date of construction. Same mortar is found in the internal wall up to Steps 61 and 62 (22.8m aOD) (Harris 2008, 31). Used as a filler behind stone in Steps 15, 16 and 59.
T2	**Hard chalk rich ragstone lime mortar no shell** Poorer quality mix than T1, regular 5-10mm chalk inclusions set in fawn sandy lime mortar. Poorer quality mix used in a large area of the step behind the irregular shaped stone steps also has flint and Kentish Ragstone rubble inclusions Occasional reused Roman tile and brick 30-80mm across	1090/93 to 1100 Steps 67 to 90 and Steps G1 to G4 (**Figures 30**, **32** and **34**): It is used as a bedding mortar between joints of each block. It is also found as a sealant up to 10mm thick covering the steps and the step edges, ensuring a flat regular impermeable surface. The poorer quality mix is used at the back of each step. Same as Type 2 mortar with little or no shell and large pieces of unburnt chalk. It is used after the building break above the external 22 to 23m aOD faces of the White Tower and above 23m aOD in the chapel (Harris 2008, 31). Type 2 mortar is clearly seen in internal stair wall of the Flamsteed Turret above 22.8m aOD above Steps 61 and 62 (Hayward pers. obs.) and also recorded in the north-west (above 22.9m aOD) and south-west (above 22.7 to 23m aOD) turrets of the White Tower (Harris, 2008, 31). One example acts as a substitute stone material completely filing gaps at the very outermost 4cm of Step 72. Its inclusion on the stairs above Step 67 indicate that Steps 67 to 89 and Steps G1 to G4 date from the later 11th century construction phase Used as a filler behind stone in Step 80

T3	**Hard white lime mortar with snail shell** Hard white lime mortar small complete coiled gastropods snails (estuarine) 5-10mm with speckles of black coal dust	1700-1900 1734-35 brick wall supporting Landing 1/Step B4 and associated sidewalls. Foundation and joint mortar for 1729-53 Portland, Purbeck and Hopton Wood stone Steps B5 to B19 and pavers for Landing 2/Step B7. Identified on the edges of Step 51 at Upper Level. Repointing the Reigate stone blocks and forming the foundation mortar of the 19th century York stone pavers
T4	**Hard Dark Grey "Roman" Cement** Extremely hard impermeable fine dark 20th century repair cement	Very late 19th to 20th century repairs. Associated with insertion of small square wooden inserts/repair in Steps 17 and 22 (**Figure 24**).
T5	**Brown Flint Pebble Concrete Mortar**	Very late 19th or 20th century repair. Only used on top of Step G6 and associated with the replacement of an earlier step by a single machine-made York stone block (**Figure 34**).
T6	**White Gritty sandy lime mortar**	18th-20th century Post-medieval repair behind stone in Step G1 (**Figure 34**)
T7	**Modern grey gravel with small brown flint pebbles mortar**	20th century repair to outermost steps of Ketton stone on Step 1 and Reigate stone on Step 2 (**Figures 21** and **22**).

Mortar types used in the Flamsteed Steps

A rather limited suite of seven mortar types (T1 to T7) were identified from the Flamsteed steps. Two primary late 11th century mortar types associated with the initial construction of the Flamsteed Turret (T1 and T2) were identified along with five 18th/19th century mortars and concretes (T3 to T7) relating to the early 18th century construction of the Steps B4 to B19 at Basement Level as well as repairs to the existing medieval fabric of Steps 1 to 90. Mortar types were found to be key for understanding the early chronological development of the Flamsteed Turret particularly because all the ceramic building material from this period were reused Roman tile and brick. Furthermore, existing studies of the internal and external mortar fabric of the White Tower (Harris 2008, 30-31) including its batter (Hayward, 2015) provided a useful body of data with which to compare the mortar samples from the Flamsteed steps. A summary of each type, their description and use in the Flamsteed Steps are summarised in the table above. The location of mortar samples (M1 to M12) is shown in **Figures 20**, **24**, **26**, **28**, **30**, **32** and **34**).

Medieval

T1 Soft crushed bivalve rich shell lime mortar

The same crushed lime shelly mortar (T1) identified up to 22.7 to 23.5m aOD of the internal and external fabric of the White Tower (Harris 2008, 30-31) was present as joint and foundation mortar in Steps 1 to 66 of the Flamsteed Turret (**Figures 22**, **24**, **26**, **28** and **30**). Step 66 (23.5m aOD) is above the 22.8m aOD recorded for the building break of the internal stair turret of Flamsteed Turret (Harris 2008, 31). This disparity in height shows that the construction break did not stop at a neat horizontal line across the Flamsteed Turret.

T2 Hard chalk rich lime mortar

Similarly, the same chalk rich lime mortar (T2) containing little or no shell as that recorded above the 22.7-23.5m aOD internal and external fabric of the White Tower (Harris 2008, 30-31), was also present from Step 67 (23.8m aOD) up to Step 90 and Steps G1 to G4 (**Figures 30**, **32** and **34**).

Thus, the 1080 to 1090/93 building break seen by changes in mortar type within the White Tower is replicated again in a study of the mortar from the stone steps in the Flamsteed Turret. The continued use of the T2 mortar type at the base of the next flight of steps (Step 90) would also support the mortar evidence from elsewhere in the White Tower (Harris, 2008, 30-31), that after the building break, the Tower's present height had been met by the late 11th century.

Post-medieval

T3 hard white shelly mortar 18th and 19th Century Mortar

This hard white shelly mortar (T3) is characteristic of 18th and 19th century builds. Although superficially similar to the T1 mortar used in Steps 1 to 66, closer inspection revealed it to contain a different type of mollusc fauna, with small complete gastropods (snails) rather than bivalves (cockles). This hard mortar type (complete with small flecks of coal) is frequently

used in builds associated with the 18th and 19th century development of London (Hayward 2017).

The early 18th century Basement Level stone steps (Steps B5 to B19) were bonded using this hard white shelly mortar (T3) as was the early 18th century brick wall supporting Step B4/Landing 1 (**Figures 20** and **22**). It was also used as repointing for the existing medieval Reigate stone. Furthermore, it is associated with 19th century York stone in Landing 5 which leads from the Flamsteed Turret to the Upper Level; to the west of Step 51 (**Figure 28**). Samples were obtained from the supporting wall below Step B4 and from Step 51 (**Figures 20** and **28**).

T4 to T7 Victorian and 20th century repair mortars

As elsewhere in the Tower, the use of a range of late Victorian and 20th century mortars and cement recipes (T4) was in response to ad-hoc repairs to the fabric. In the Flamsteed Steps, repairs are small scale and limited to individual steps at Landing 2/Step B7 and Steps 1, 2, 17, 22, G1 and G6 (**Figures 20**, **22**, **24** and **34**). Samples were not taken of mortar T4 to T7.

APPENDIX 3: OASIS FORM

OASIS ID: preconst1-318573

Project details

Project name	Historic Building Recording of the Stairs of The Flamsteed Turret, The White Tower, Tower of London
Short description of the project	Pre-Construct Archaeology was commissioned by Historic Royal Palaces to undertake building recording during the replacement of the protective timber staircase in the Flamsteed Turret at the White Tower, Tower of London. The timber covers and the underlying stone stair vice built from 1075/79 to 1100 were recorded. Petrological analysis of the steps identified the same 1080 to 1090/93 building break as that seen elsewhere in the fabric of the White Tower around 23m aOD. This hiatus was identified by a change in mortar in the steps and surrounding turret wall (also marked by ashlar blocks to stone rubble construction). Although malmstone was the principal stone-type associated with the medieval steps, it was not used above the building break. Caen stone, Reigate stone and Quarr stone with crisp axe carving were used in the steps approaching the building break. Above the building break, Reigate stone was the most commonly used with Quarr stone and some Bembridge Limestone. The Basement Level steps are late post-medieval in date. The watching brief established that older timber covers still exist over Step 90 to 105 at Gallery Level. The oak covers below Step 90 were late 20th century in appearance with steel nosings housing grit treads. Faint graffiti on one of the timber treads of '1971' may suggest the date that they replaced the earlier scheme. Graffiti on one step showed that it was lifted on 04/04/1991. Datable finds under the covers included a 1960 shilling, 1995 and 2001 tickets and a 2007 leaflet.
Project dates	Start: 02-01-2018 End: 05-06-2018
Previous/future work	Yes / No
Any associated project reference codes	TOL169 - Sitecode
Type of project	Building Recording
Site status	World Heritage Site
Site status	Area of Archaeological Importance (AAI)
Site status	Conservation Area
Site status	Listed Building
Current Land use	Other 2 - In use as a building
Monument type	FORTRESS Medieval

Project location

Country	England
Site location	GREATER LONDON TOWER HAMLETS TOWER HAMLETS The Flamsteed Turret, The White Tower, Tower Hill, London, EC3N 4AB

Postcode	EC3N 4AB
Study area	225 Square metres
Site coordinates	TQ 33633 80568 51.507721011557 -0.074213018176 51 30 27 N 000 04 27 W Point

Project creators

Name of Organisation	Pre-Construct Archaeology Limited
Project brief originator	Historic Royal Palaces
Project design originator	George Roberts
Project director/manager	Charlotte Matthews
Project supervisor	Kevin Hayward
Project supervisor	Alfred R. J. Hawkins
Type of sponsor/funding body	Historic Royal Palaces
Name of sponsor/funding body	Historic Royal Palaces

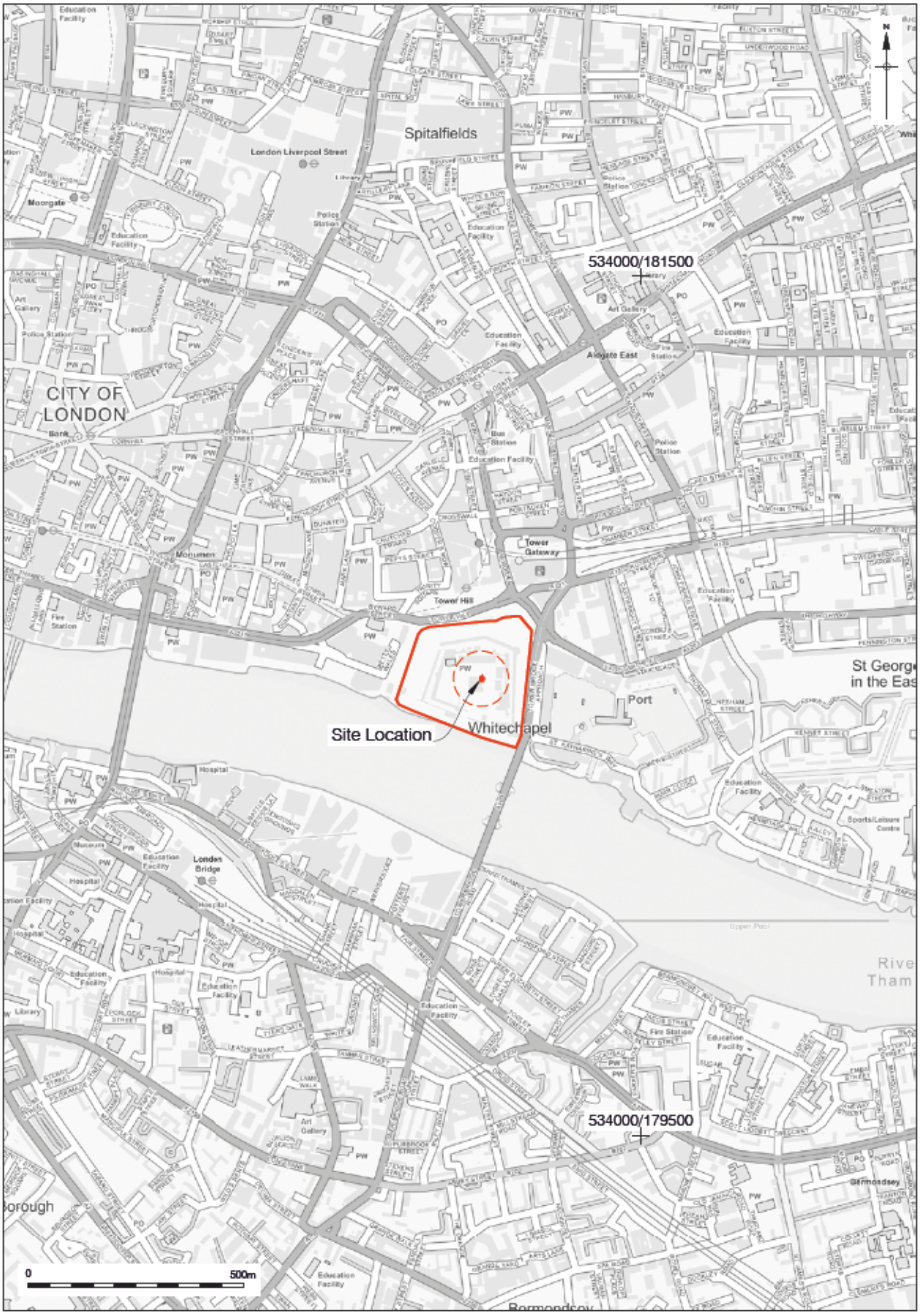
Project archives

Physical Archive recipient	Historic Royal Palaces
Physical Archive ID	3910079/TOL169
Physical Contents	"other"
Digital Archive recipient	Historic Royal Palaces
Digital Archive ID	3910079/TOL169
Digital Contents	"none"
Digital Media available	"Images raster / digital photography","Text"
Paper Archive recipient	Historic Royal Palaces
Paper Archive ID	3910079/TOL169
Paper Contents	"none"
Paper Media available	"Aerial Photograph","Map","Photograph","Plan","Report"

Project bibliography 1

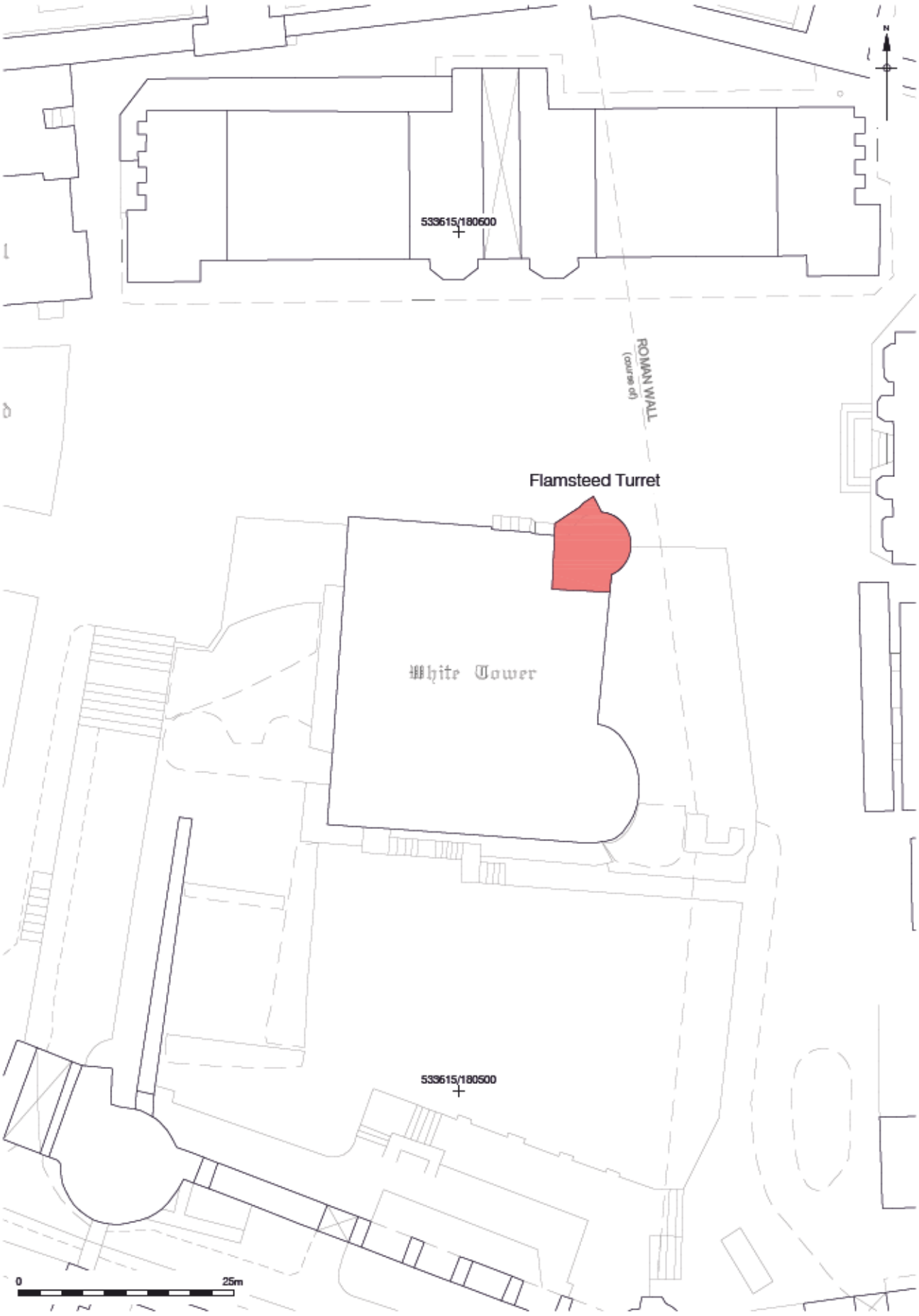
Publication type	Grey literature (unpublished document/manuscript)

Title	Historic Building Recording and Watching Brief on the repair (Phase II) of the Flamsteed Turret Steps in the White Tower, HM Tower of London, London Borough of Tower Hamlets
Author(s)/Editor(s)	Hayward, K. and Hawkins, A.
Other bibliographic details	PCA Report Number: R13279
Date	2018
Issuer or publisher	Pre-Construct Archaeology
Place of issue or publication	Brockley, London
Description	A4 PDF report
Entered by	Charlotte Matthews (cmatthews@pre-construct.com)
Entered on	31 July 2018



12/05/17 MR

Figure 1
Site Location
1:12,500 at A4



23/07/18 MR

Figure 2
Detailed Site Location
1:625 at A4

WEST

EAST

OBSERVATORY

OBSERVATORY LEVEL 37.150

ROOF LEVEL 33.080

MID LEVEL G-R PLAN

NORTHERN MURAL PASSAGE

GALLERY LEVEL 26.540

MID LEVEL U-G PLAN

UPPER LEVEL 20.990

MID LEVEL E-U PLAN

ENTRANCE LEVEL 15.400

BASEMENT LEVEL 8.400

LANDING OF OBSERVATORY LEVEL- 37.150

START OF KITE STAIR

10 RISERS IN 1720

40 RISERS IN 7600

LANDING OF GALLERY LEVEL- 27.690

26 RISERS IN 6990

STAIR LANDING- 20.640

PRINCIPAL AREA OF REPAIRS

LANDING OF ENTRANCE LEVEL- 15.960

25 RISERS IN 4360

LANDING 3- 11.620

25 RISERS IN 4340

LANDING 2- 9.680

3 RISERS IN 590

LANDING 1- 9.090

4 RISERS IN 690

TREAD NUMBERS

52A

Figures 33, 34 & 40

Figures 31, 32 & 40

Figures 29, 30 & 39

Figures 27, 28 & 38

Figures 25, 26 & 37

Figures 23, 24 & 36

Figures 21, 22 & 35

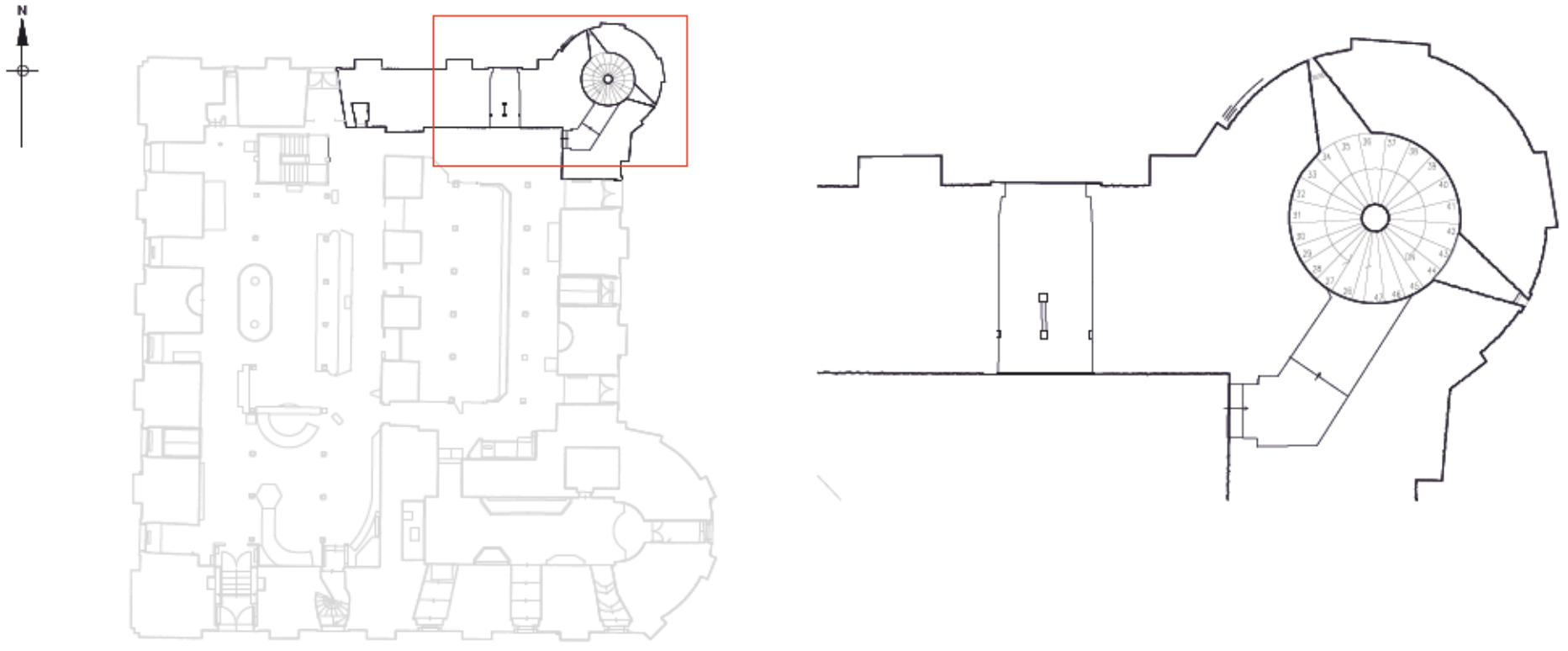
Figures 19, 20 & 35

0 4 12 Feet
0 2 4 Metres

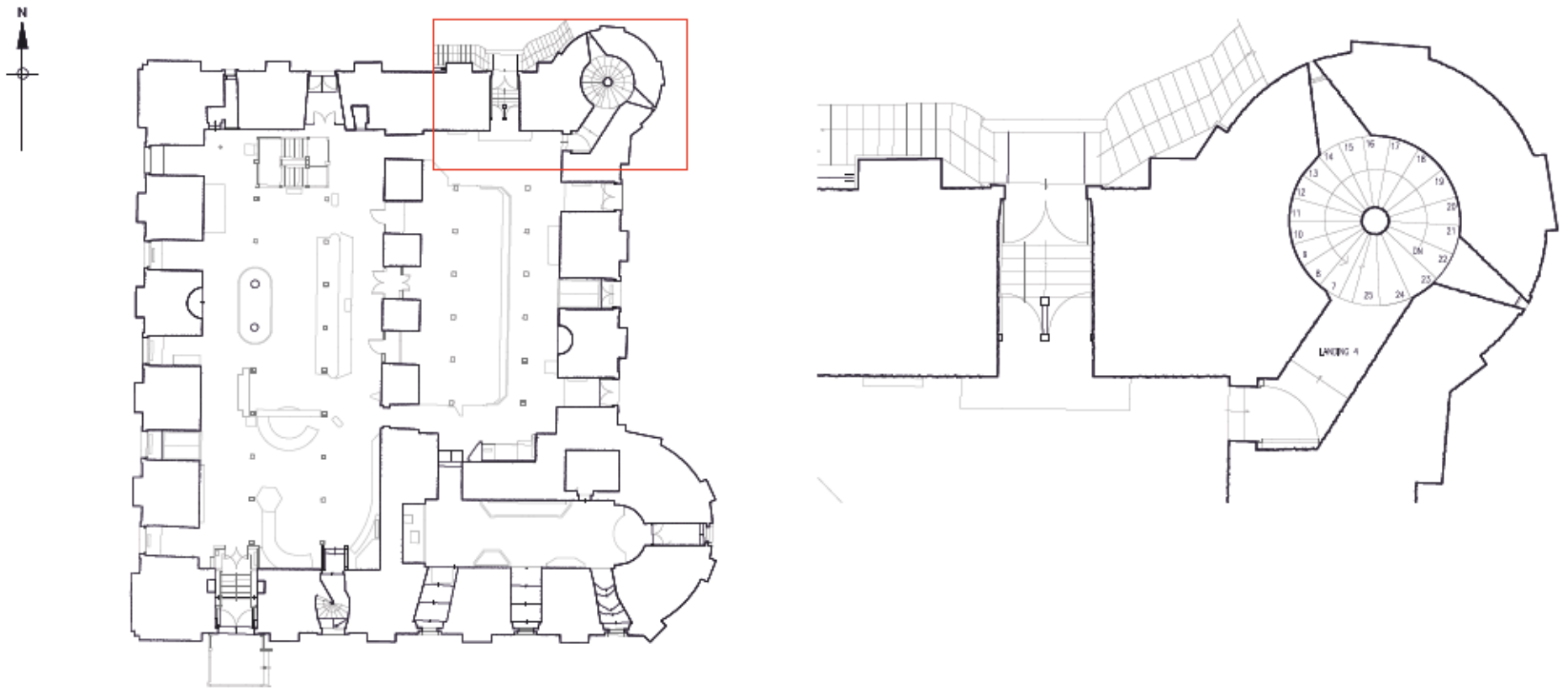
23/07/18 MR

Figure 3
Flamsteed Turret Section
1:125 at A3

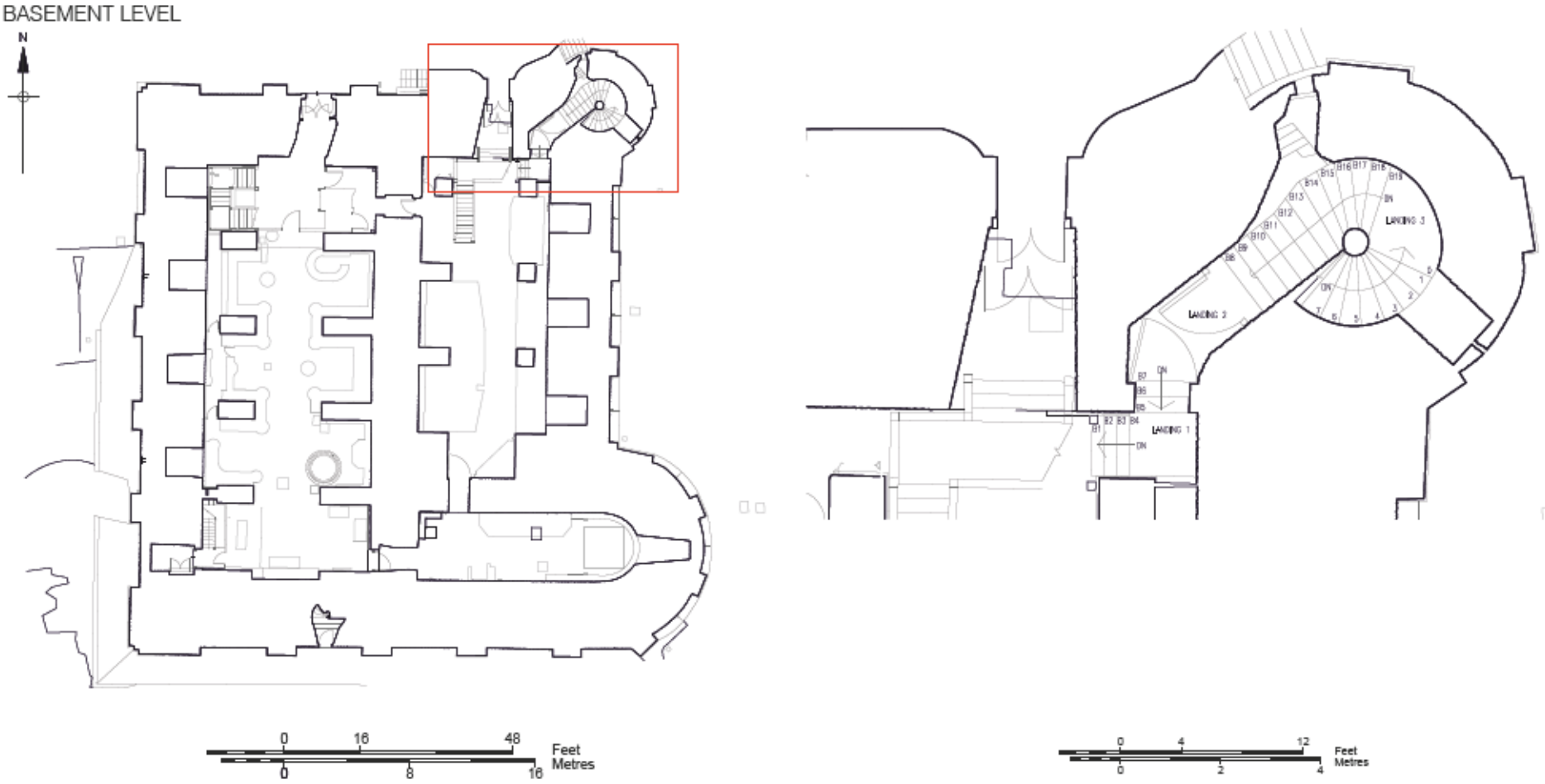
MID LEVEL E-U (ENTRANCE TO UPPER LEVELS)



ENTRANCE LEVEL



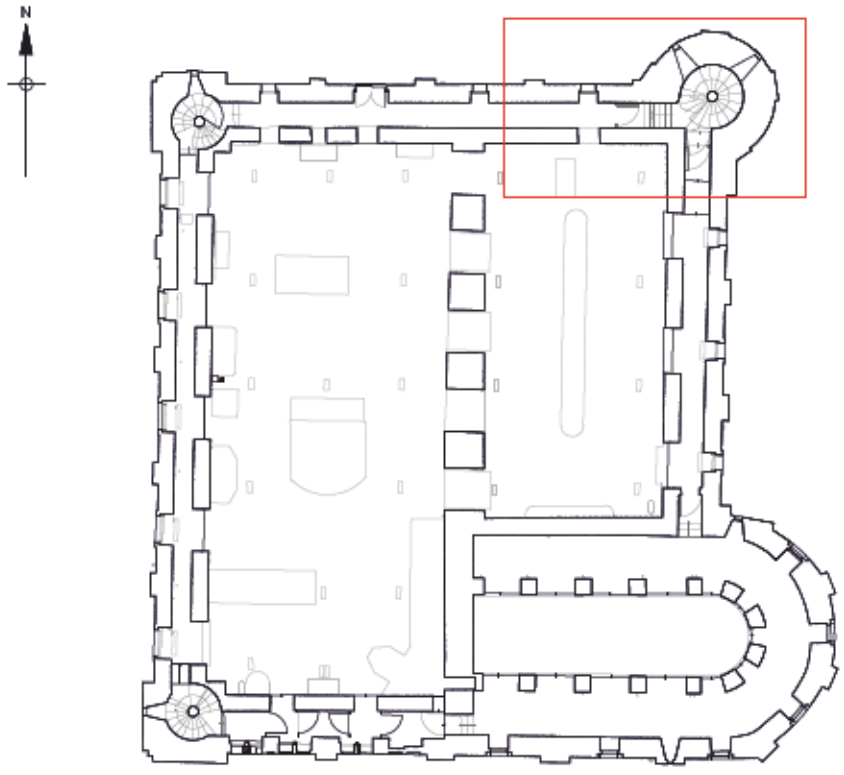
BASEMENT LEVEL

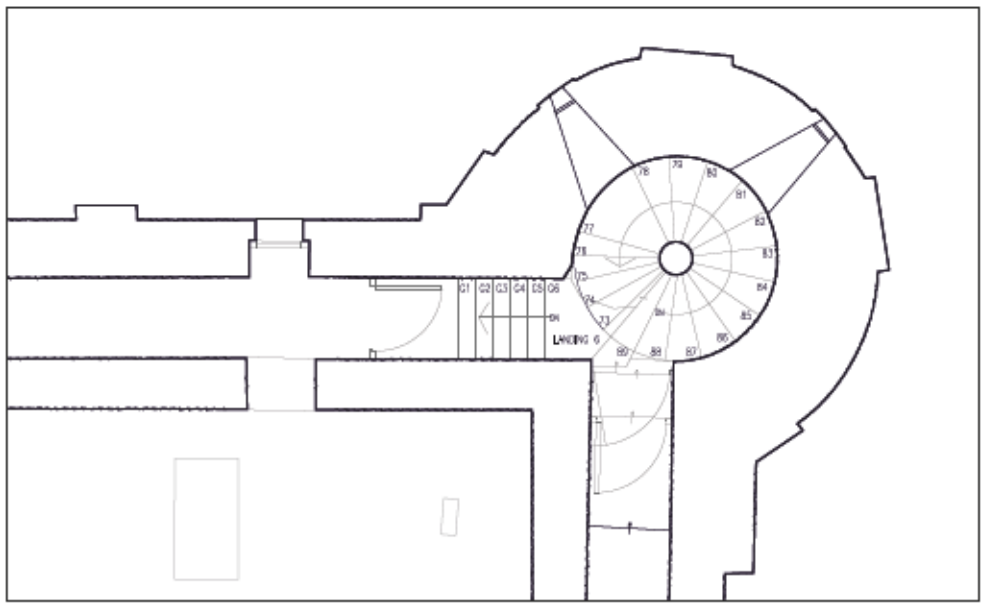


26/07/18 MR

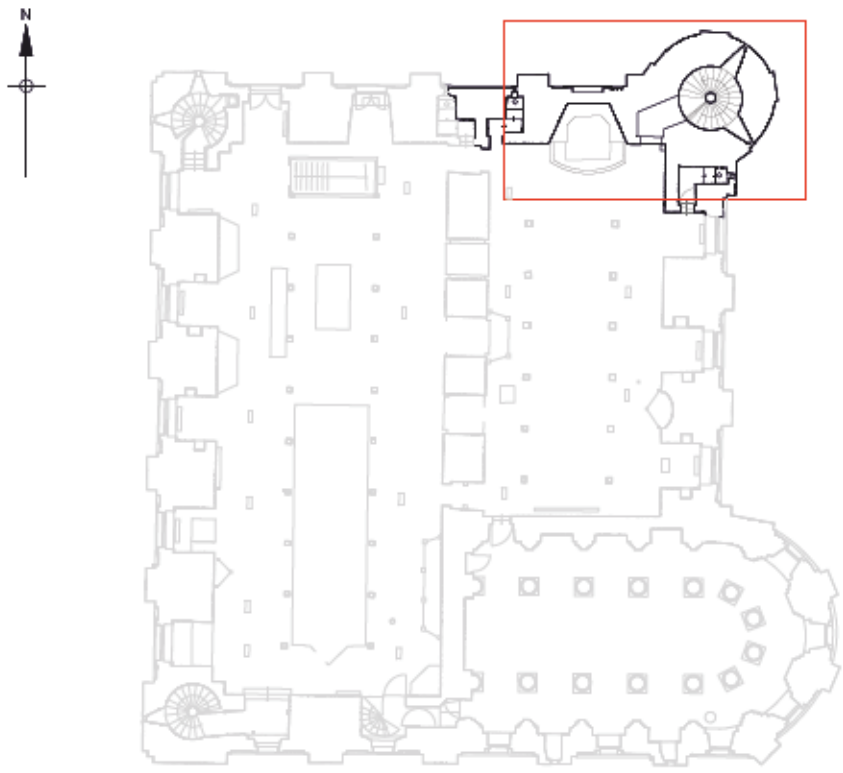
Figure 4
Flamsteed Turret Floor Plans, Basement to Mid Level E-U
Plans - 1:400, Detail plans - 1:125 at A3

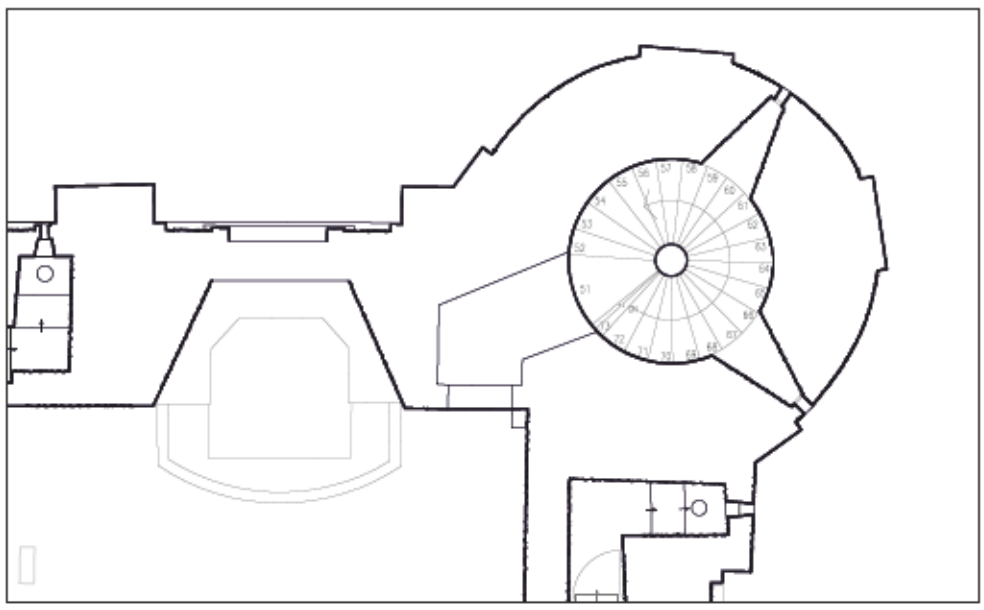
GALLERY LEVEL





MID LEVEL U-G (UPPER TO GALLERY LEVELS)





UPPER LEVEL

0 16 48 Feet
0 8 16 Metres

0 4 12 Feet
0 2 4 Metres

26/07/18 MR

Figure 5
Flamsteed Turret Floor Plans, Upper Level to Gallery Level
Plans - 1:400, Detail plans - 1:125 at A3

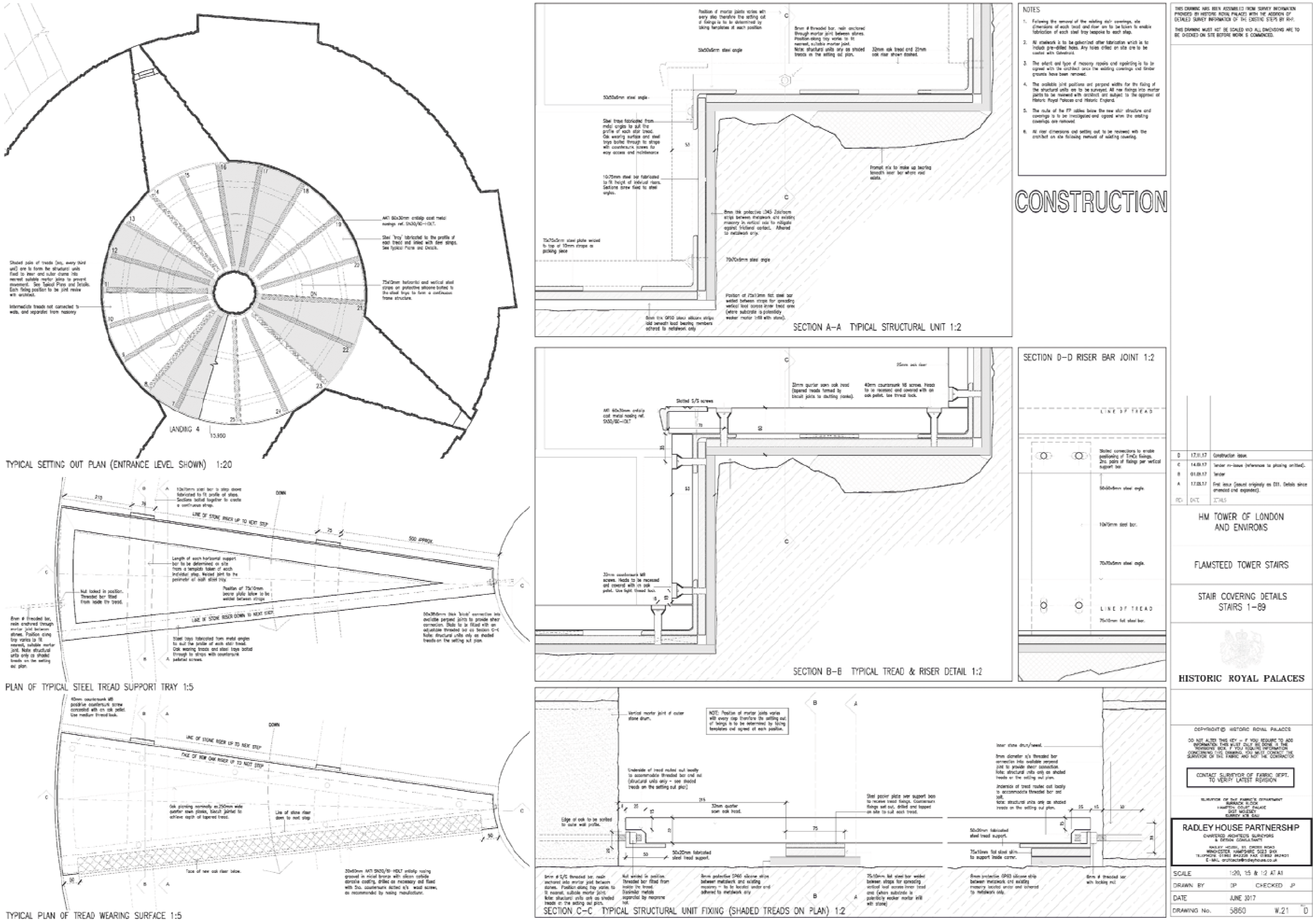


Figure 6
Construction Plan for New Stair Covers
(not to scale)

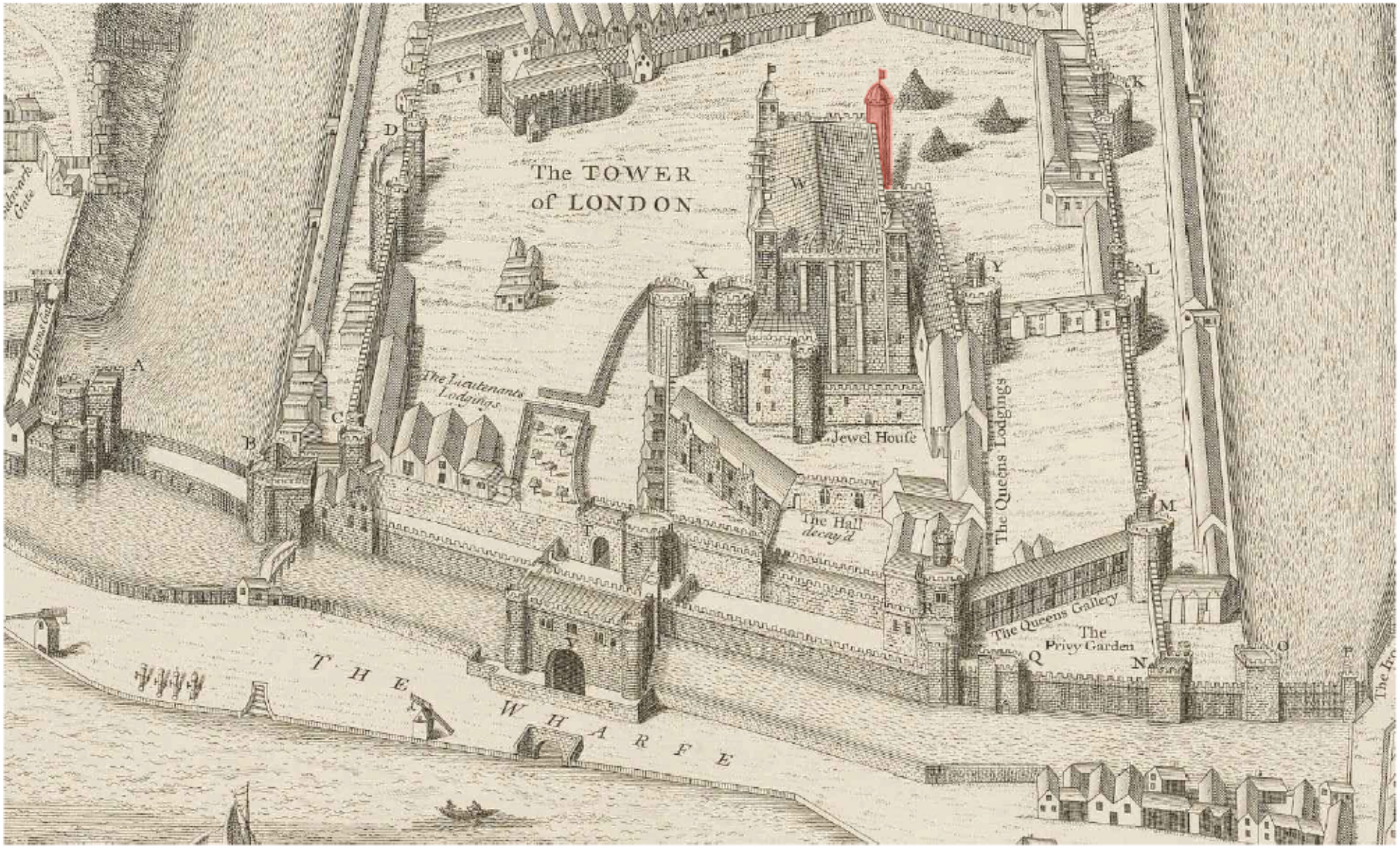


Figure 7
Copy of Haiward and Gascoyne's Survey of 1597 made for the Society of Antiquaries in 1741
(The Society of Antiquaries of London)
(no scale)

27/07/18 MR

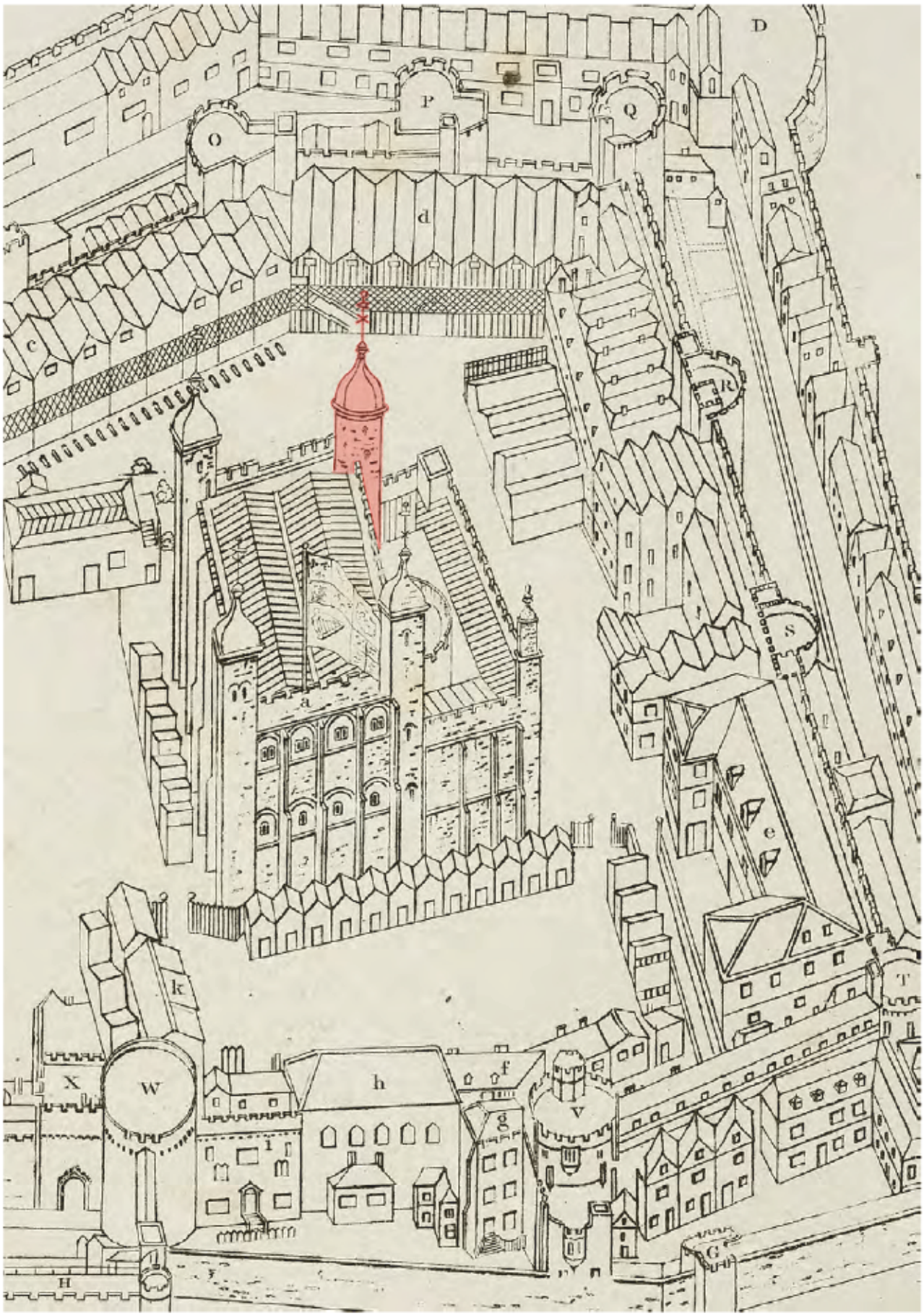


Figure 8
Detail of Holcroft Blood's 'birds-eye' view of the Tower, 1688
(no scale)

27/07/18 MR

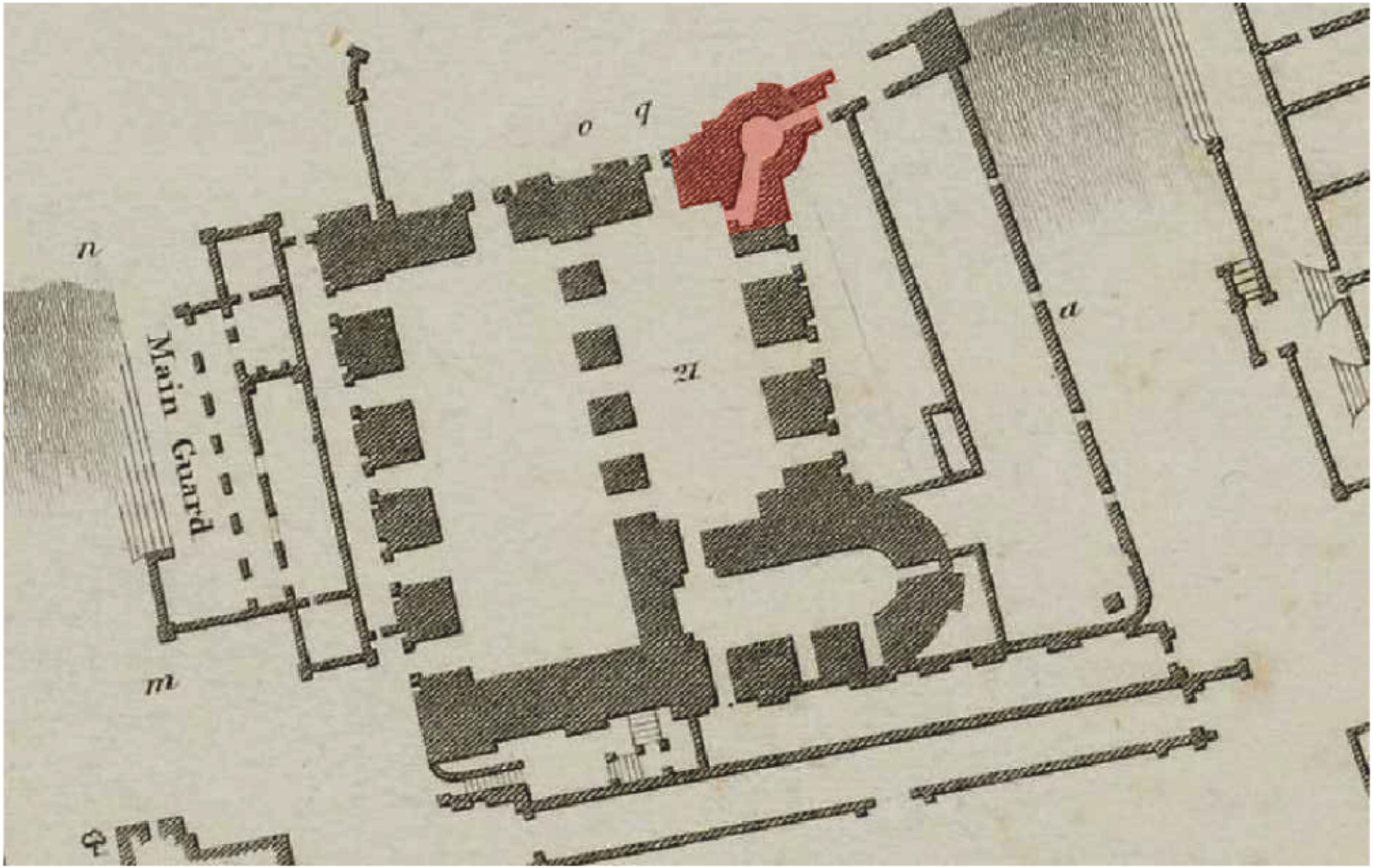


Figure 9
1726 Basement Plan of the White Tower by Clement Lempiére printed in 1815 (© British Museum)
(no scale)

27/07/16 MR

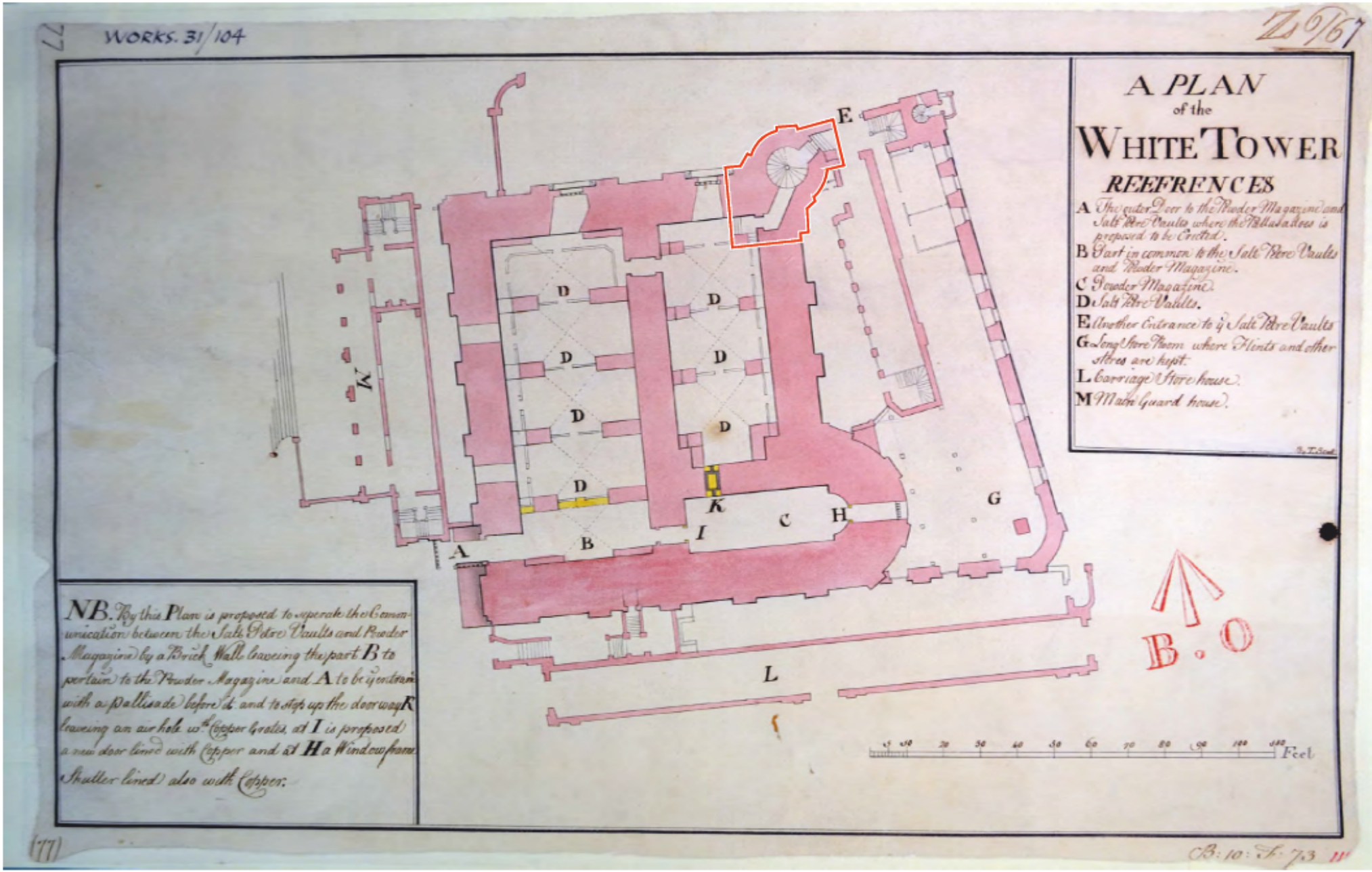


Figure 10
Early 18th century (before 1754) Basement Plan of the White Tower by T. Scott (©TNA 31/104)
(not to scale)

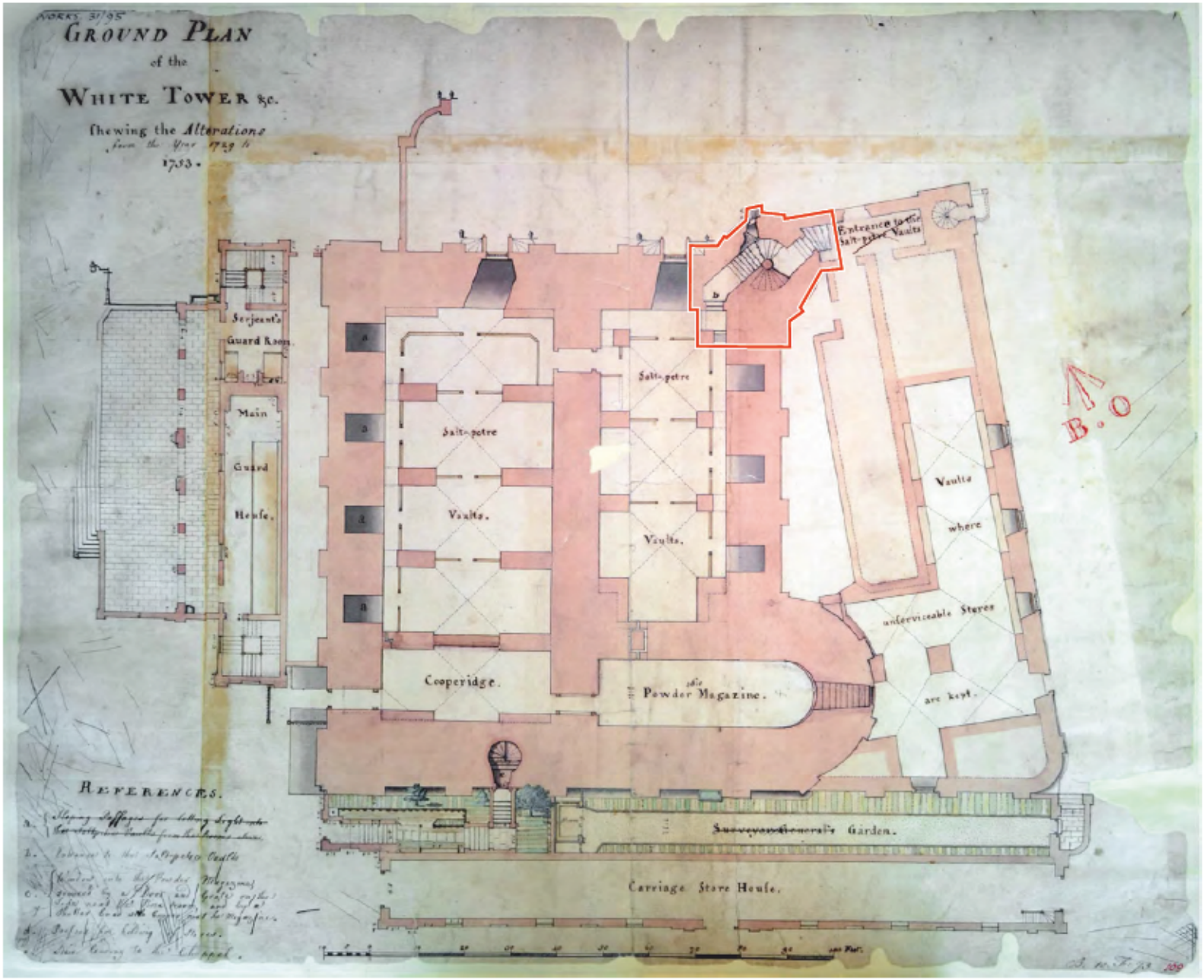


Figure 11
1754 Basement Plan of the White Tower showing alterations between 1729 and 1753 (©TNA 31/95)
(not to scale)

27/07/18 MR

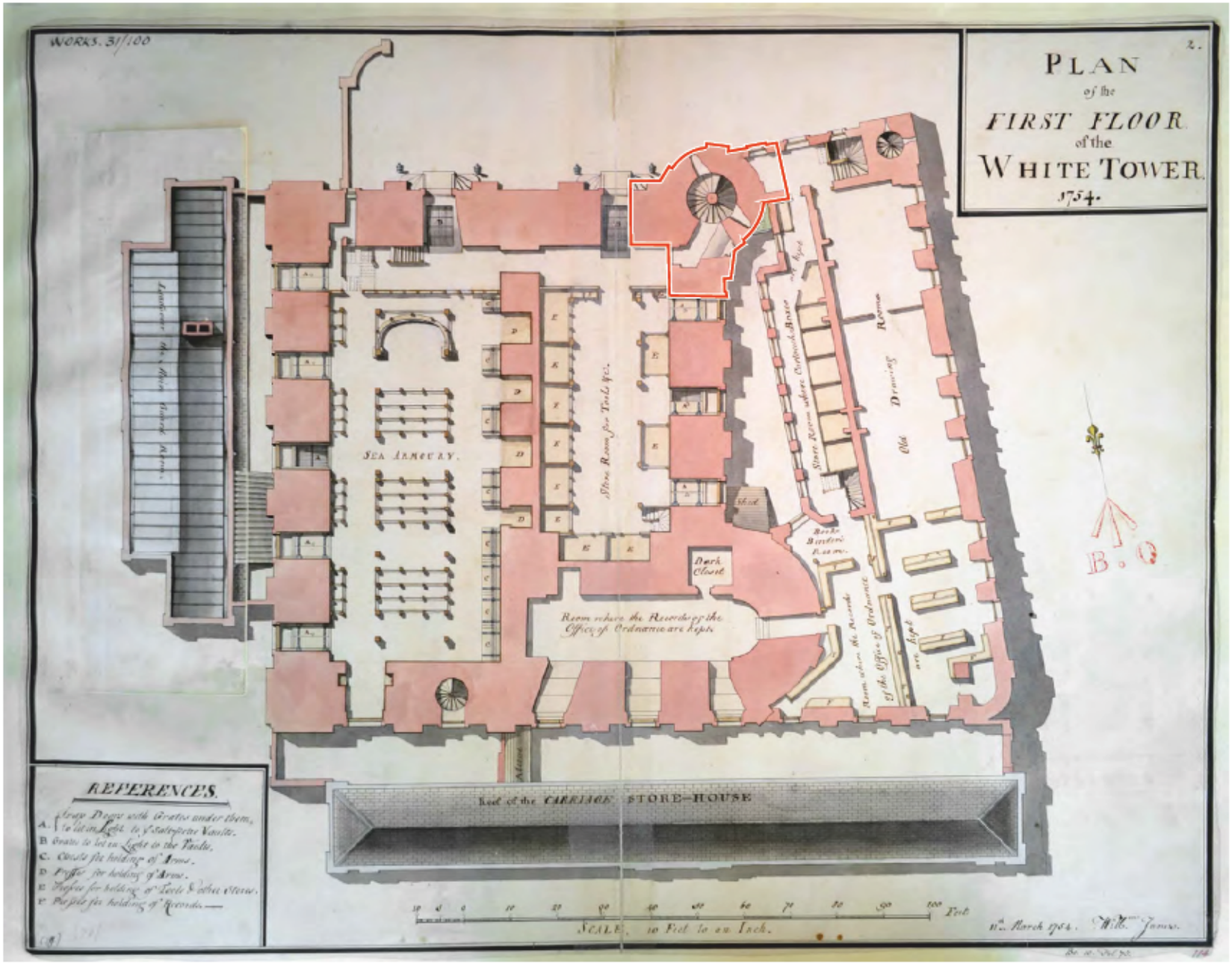


Figure 12
1754 Entrance Level Plan of the White Tower by William James (© TNA WORK 31/100)
(not to scale)

27/07/18 MR

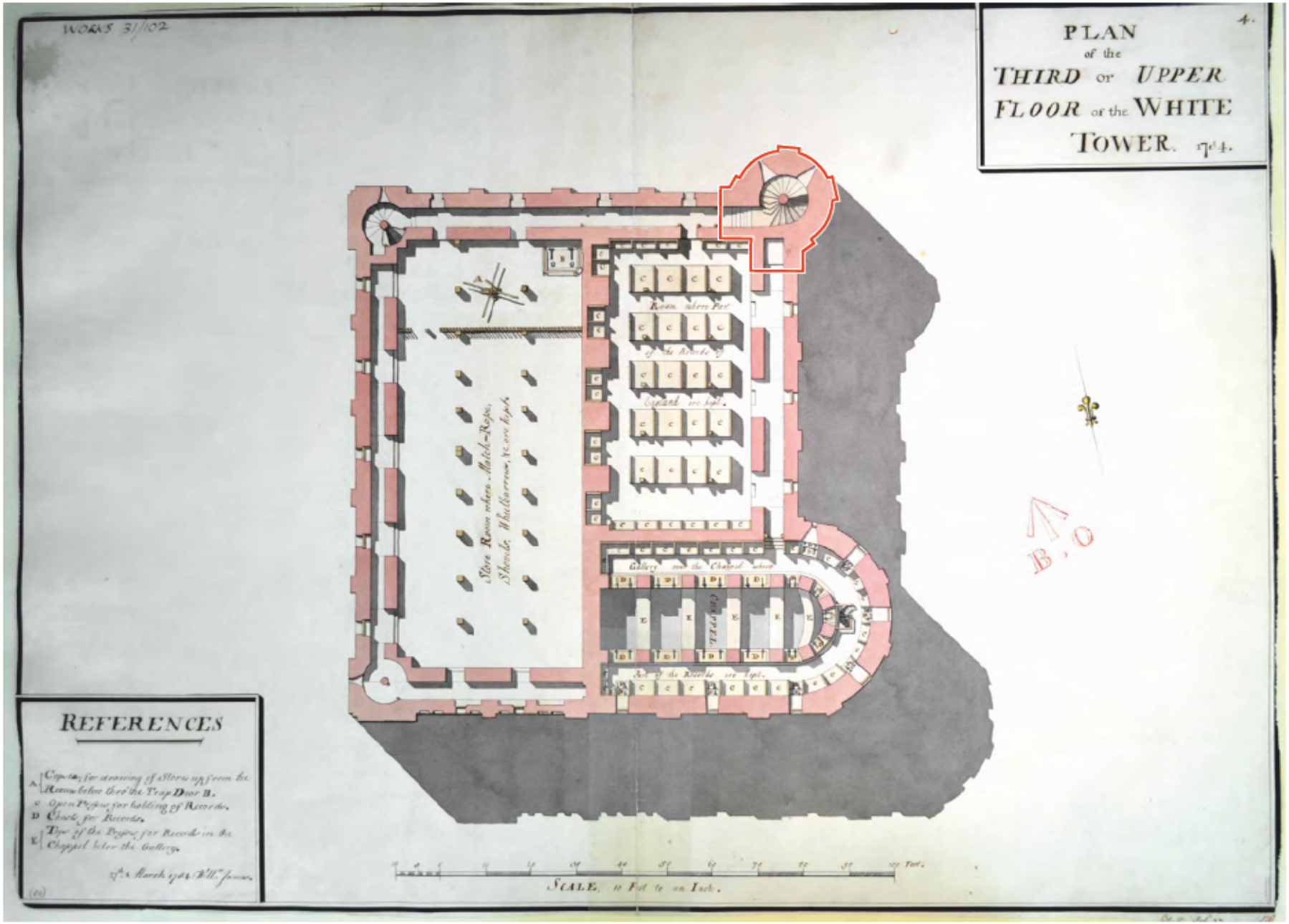


Figure 13
1754 Gallery Level Plan of the White Tower by William James (WORK 31/102)
(not to scale)

27/07/18 MR

Figure 14
Frederick Nash lithograph of the White Tower, 1820
(no scale)

27/07/16 MR

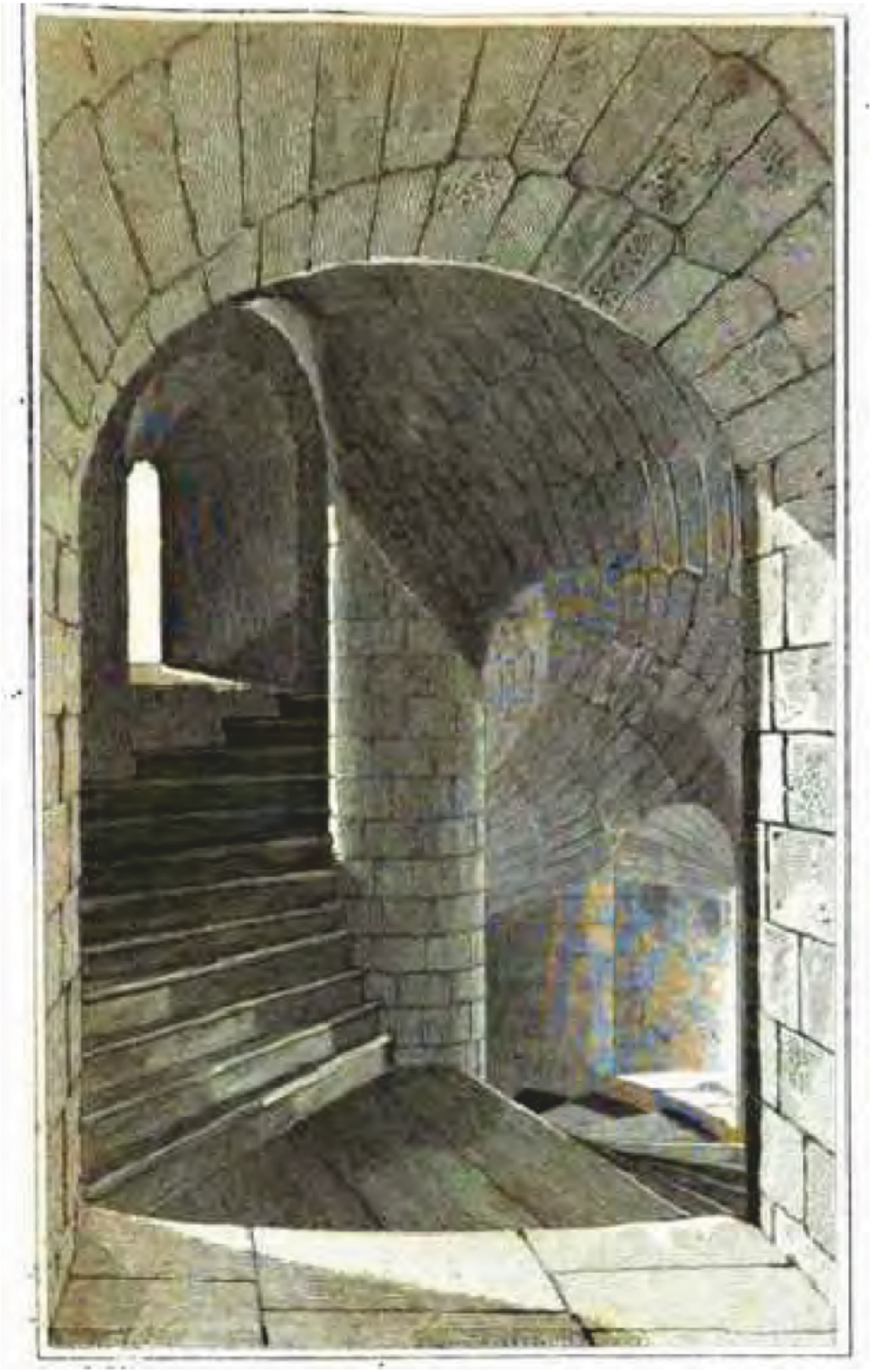
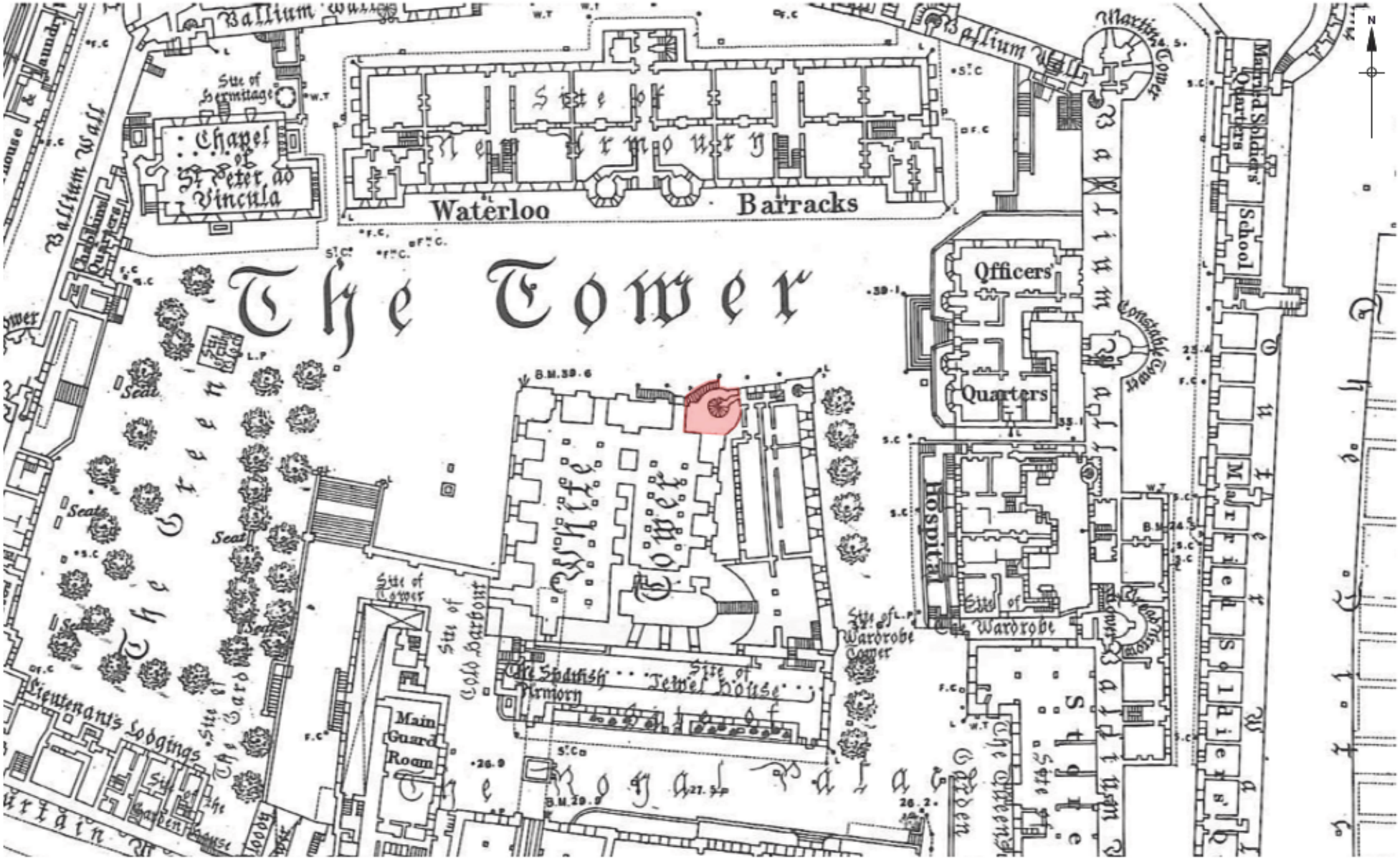


Figure 15
View of the vice in the Flamsteed Tower showing the wooden covering, as published in Bayley, *c.*1821
(no scale)

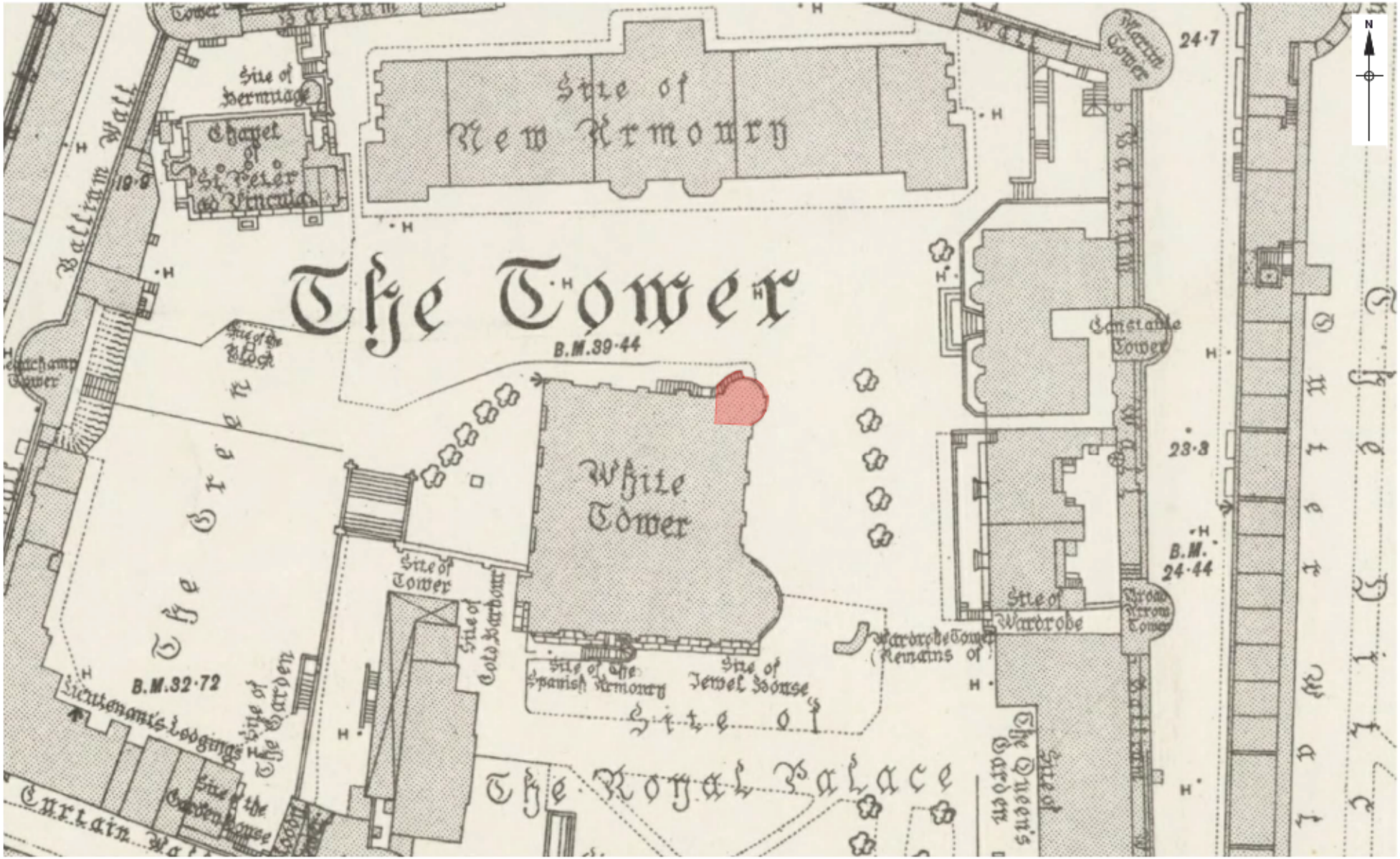
Figure 16
The Flamsteed Steps - Archer, 1851 (BM, 1874, 0314.287)
(no scale)



0 40m

27/07/18 MR

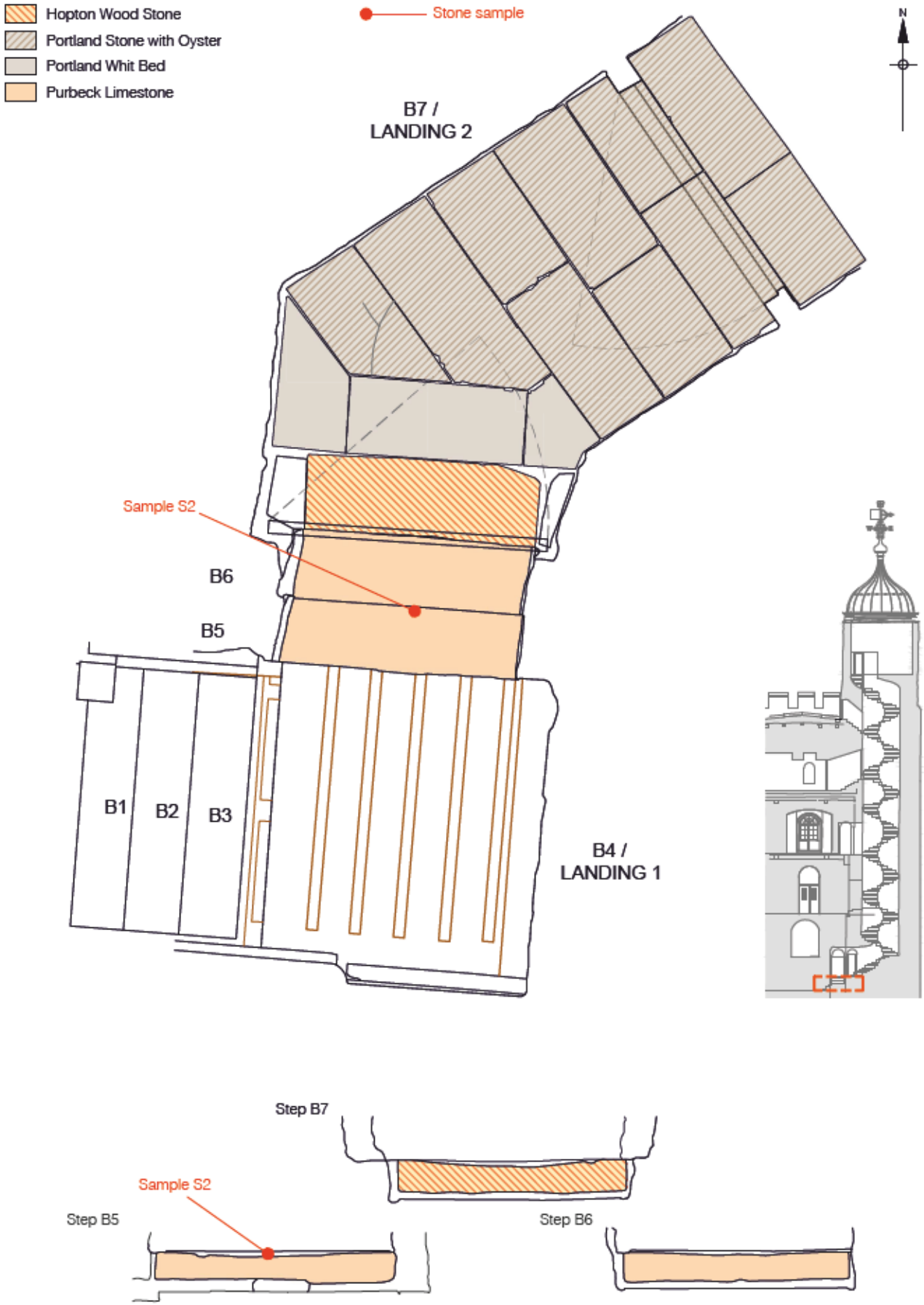
Figure 17
First Edition Ordnance Survey map, 1872-73
1:800 at A4



0 40m

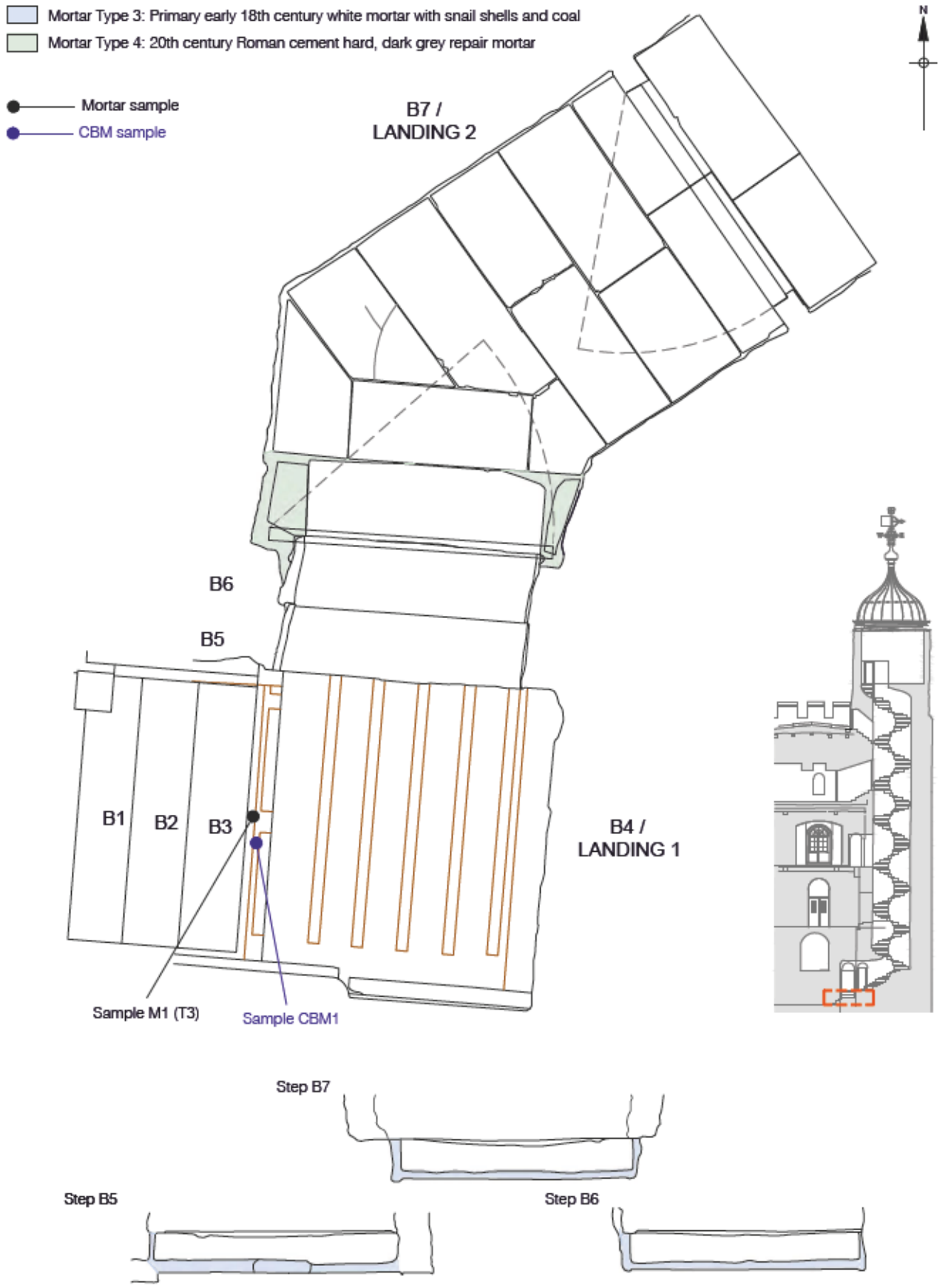
27/07/18 MR

Figure 18
Second Edition Ordnance Survey map, 1896
1:800 at A4



05/06/18 MR & 02/07/18 MS

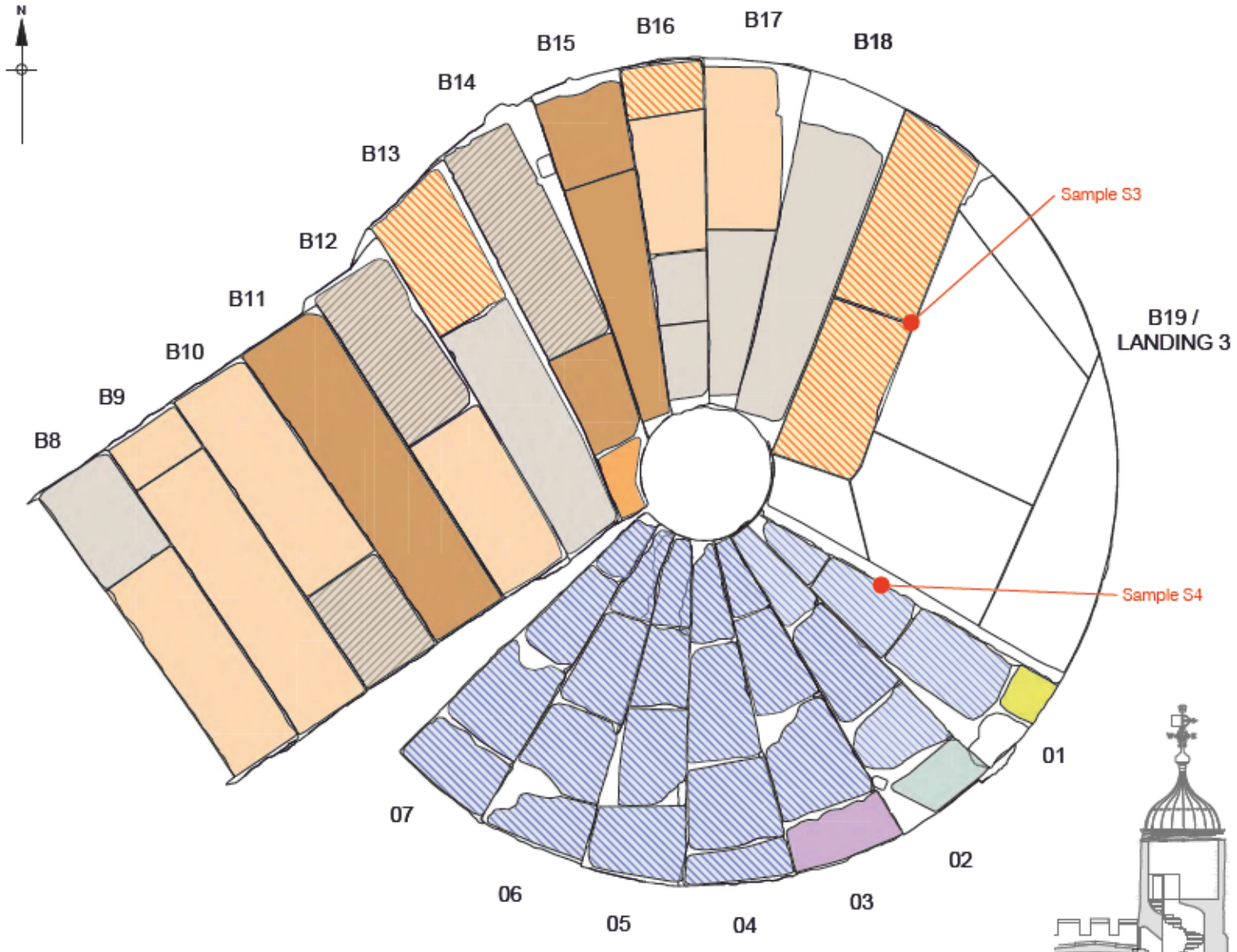
Figure 19
Plan of B1 to B7 and Elevations of Steps B5 to B7 (Landing 2): Stone Types with inset showing location of stairs
1:25 at A4

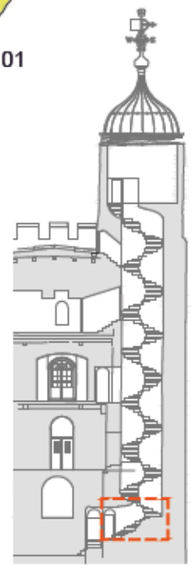


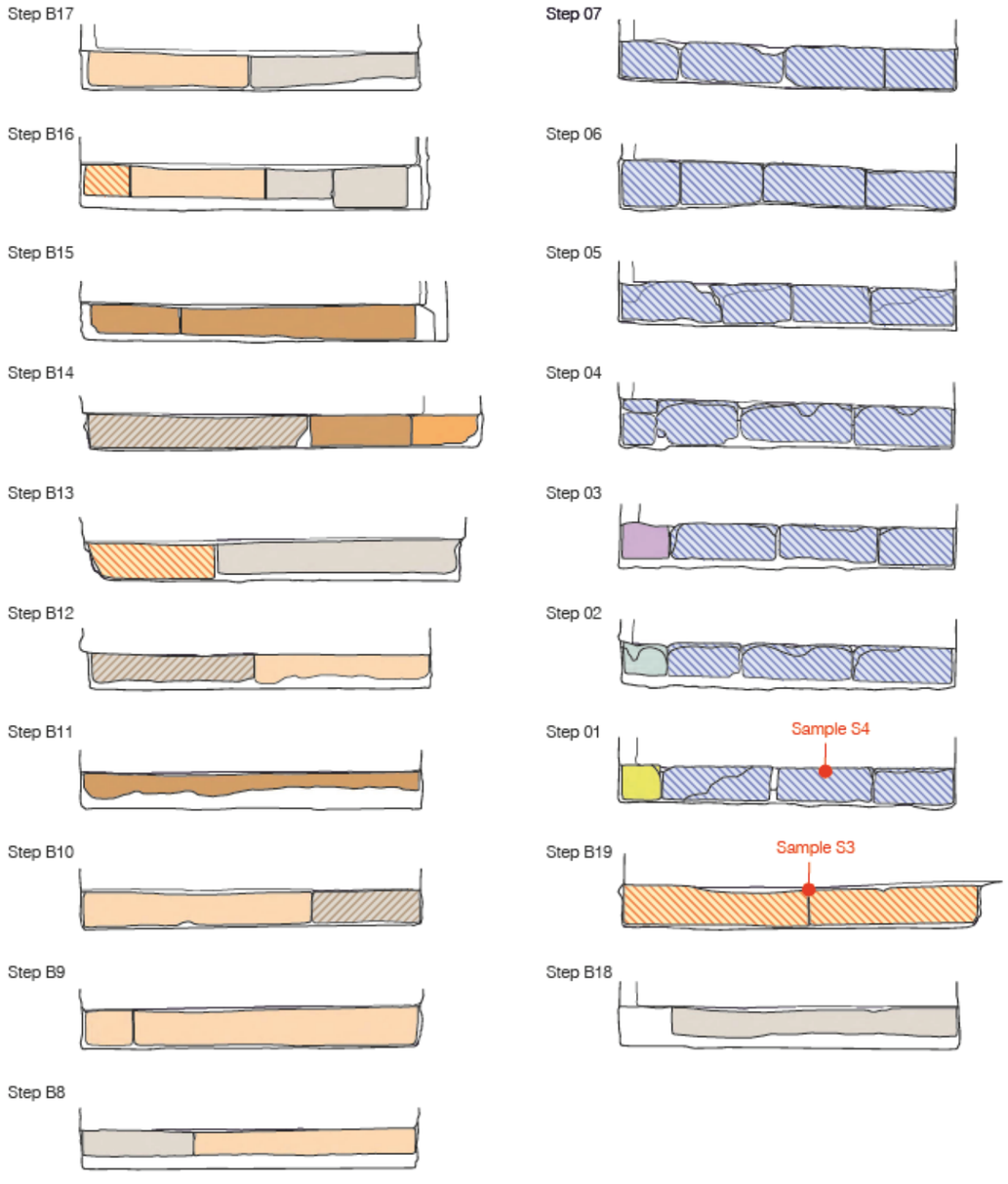
05/06/18 MR & 02/07/18 MS

Figure 20
Plan of B1 to B7 and Elevations of B5 to B7 (Landing 2): Mortar Types with inset showing location of stairs
1:25 at A4

Caen stone
Hopton Wood Stone
Ketton stone
Malmstone
Portland Stone with Oyster
Portland Whit Bed
Purbeck Limestone
Purbeck Limestone - Thornback
Purbeck Marble
Reigate stone
Stone sample





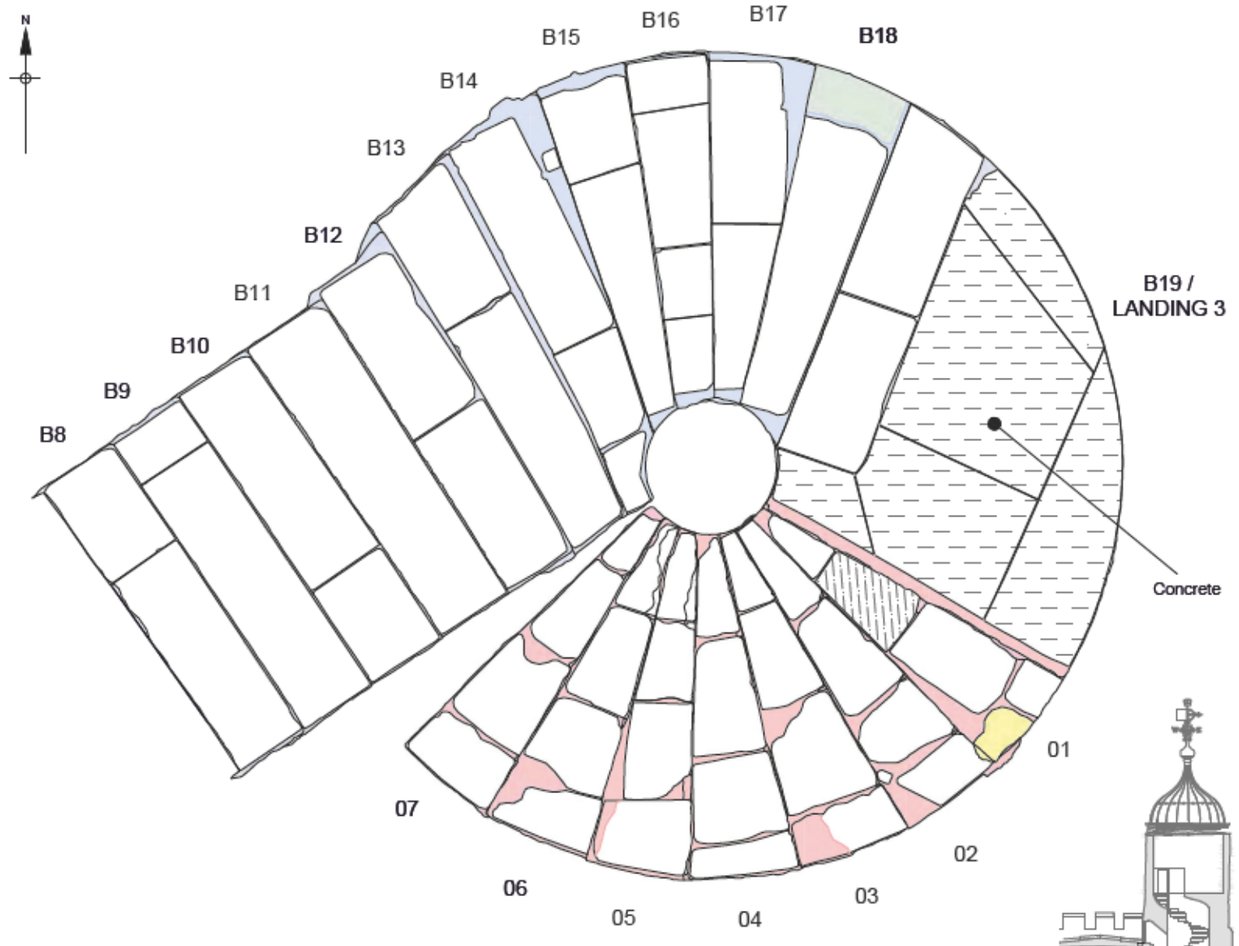


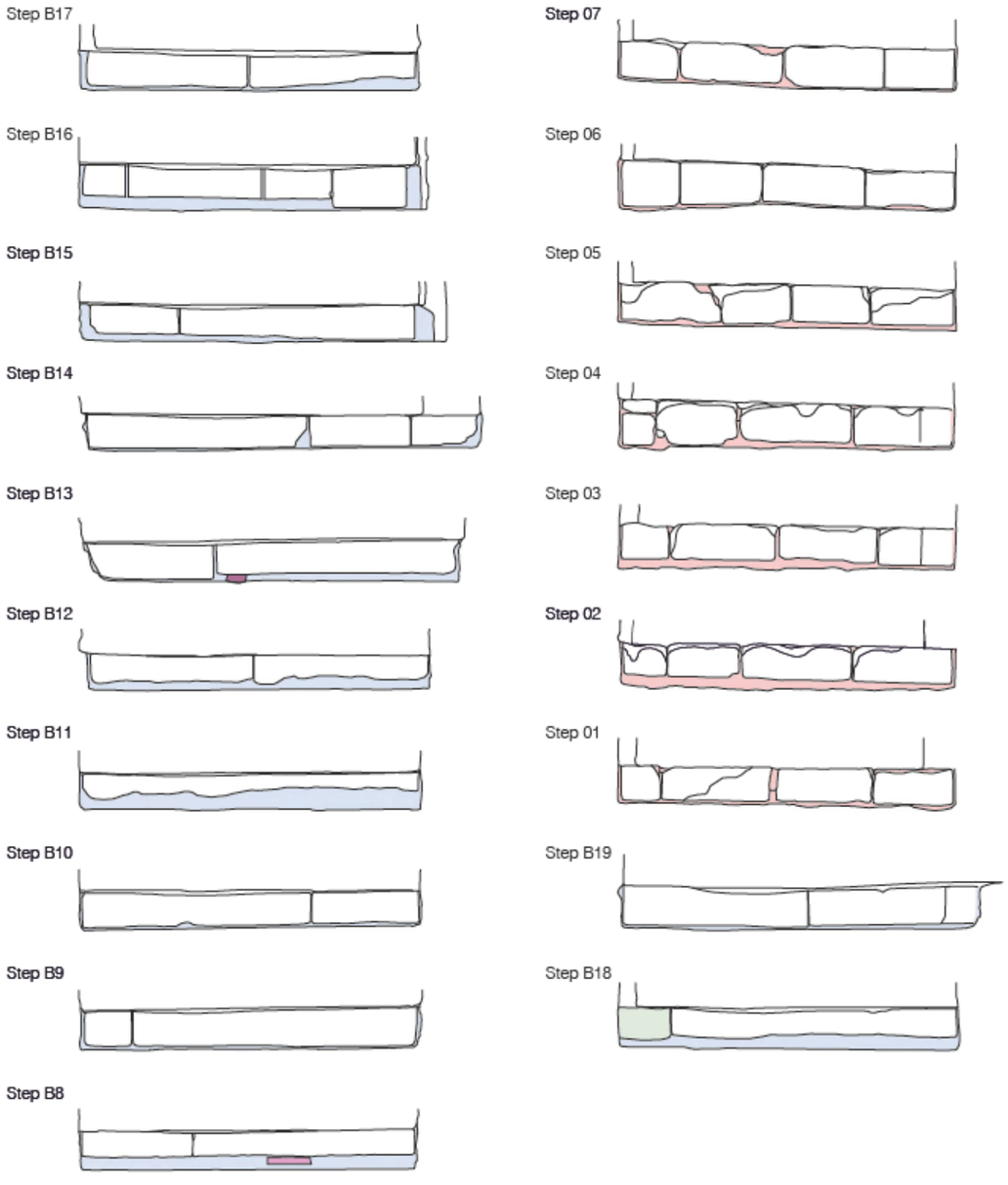
Feet
Metres

05/06/18 MR & 05/07/18 MS

Figure 21
Plan and Elevations of Steps B8 to B19 (Landing 3) and 1 to 7: Stone Types
with inset showing location of stairs
1:25 at A3

Mortar Type 1: Primary Medieval shell mortar
Mortar Type 3: Primary early 18th century white mortar with snail shells and coal
Mortar Type 4: 20th century Roman cement hard, dark grey repair mortar
Mortar Type 7: Late 19th / early 20th century grey gravel mortar with small brown flint pebbles
Post Medieval Peg Tile
Tudor brick
Tool Marks



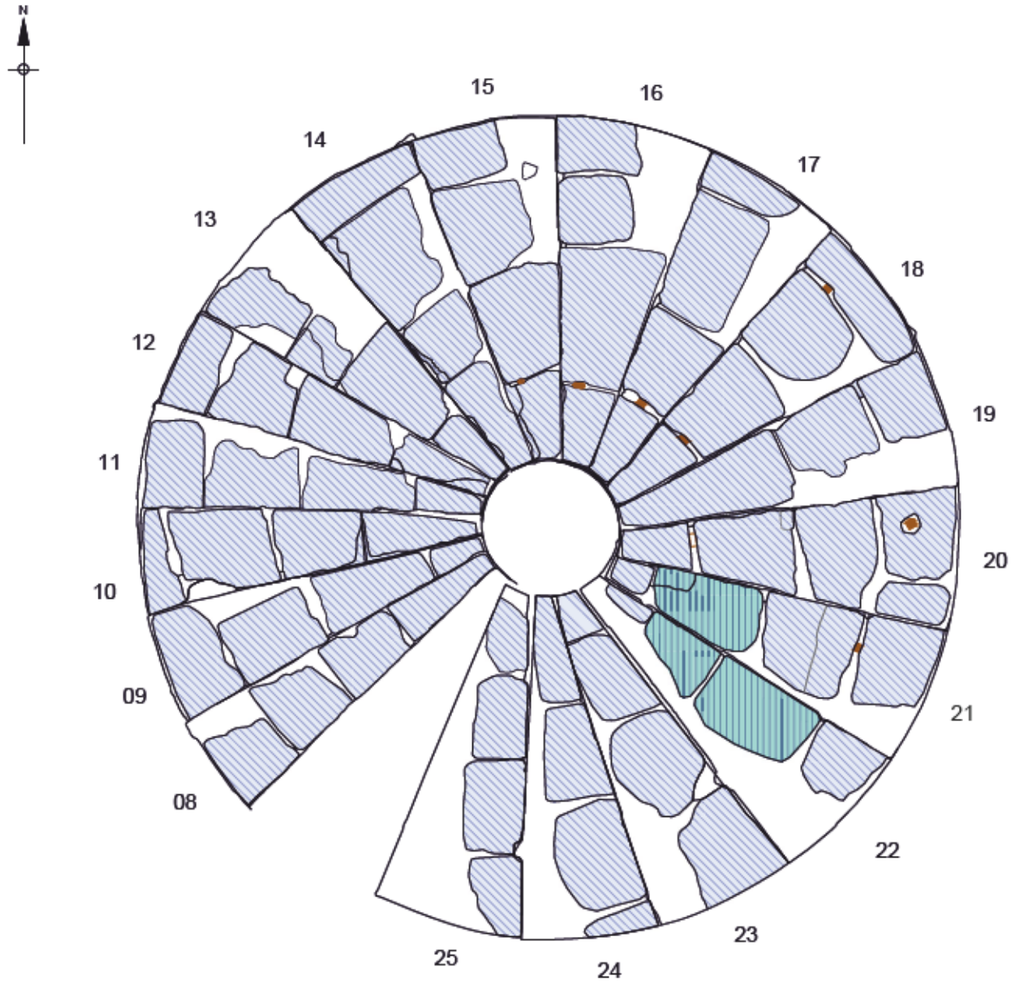


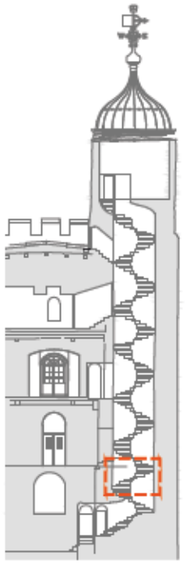
Feet
Metres

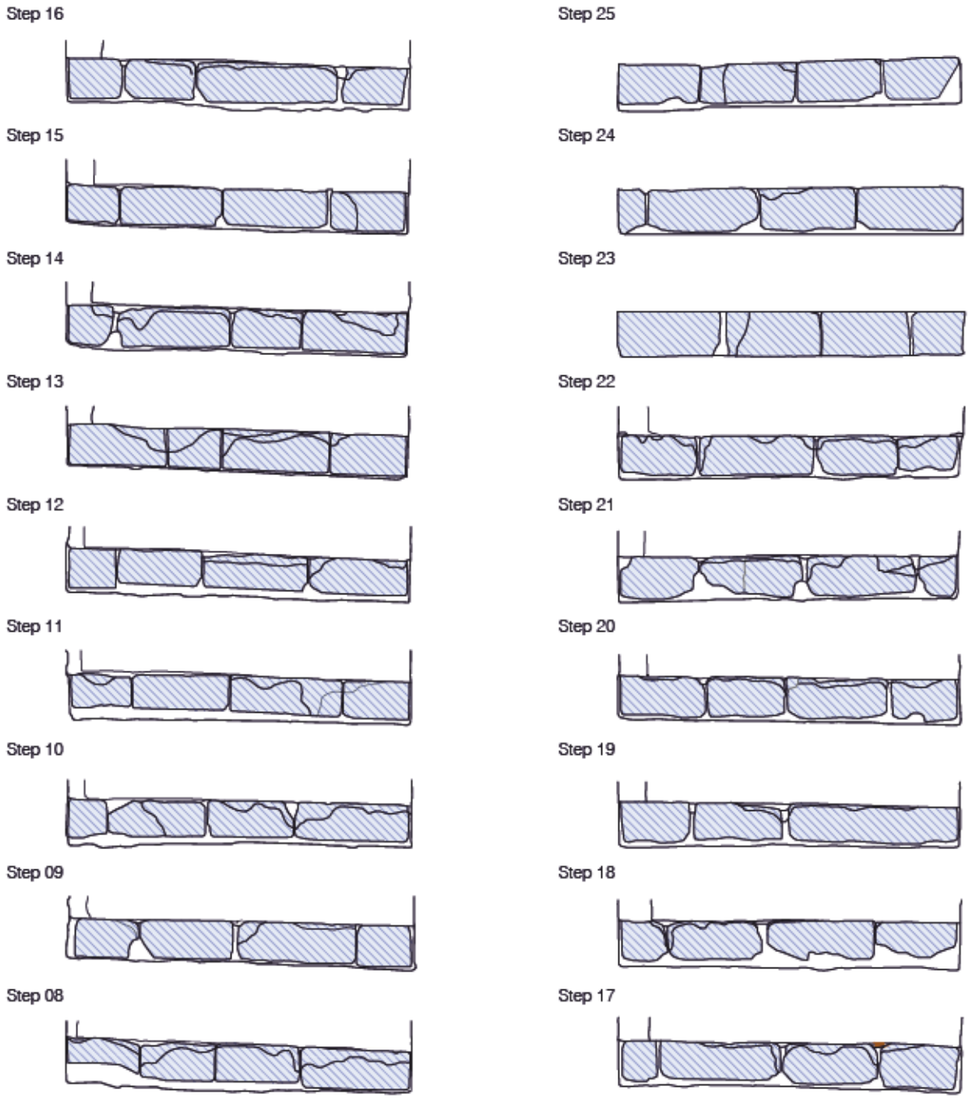
05/06/18 MR & 06/07/18 MS

Figure 22
Plan and Elevations of Steps B8 to B19 (Landing 3) and 1 to 7: Mortar Types with inset showing location of stairs
1:25 at A3

Malmstone
Unidentified Shelly Limestone
Wood







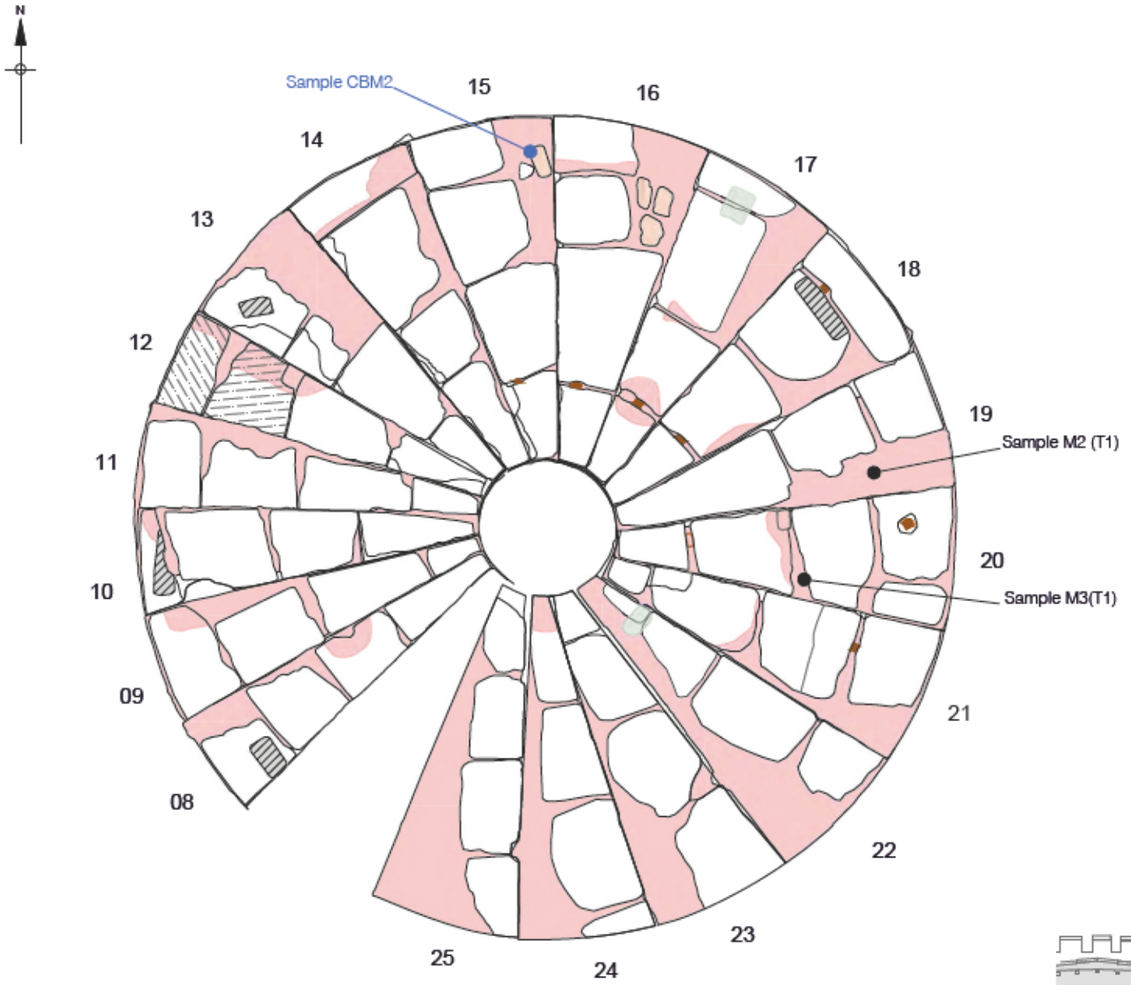
0 1 3 Feet
0 0.5 1 Metres

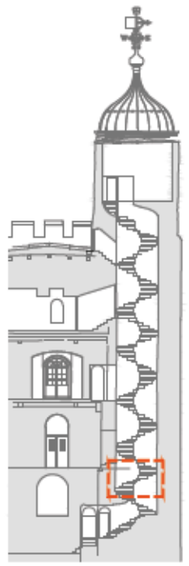
05/06/18 MR

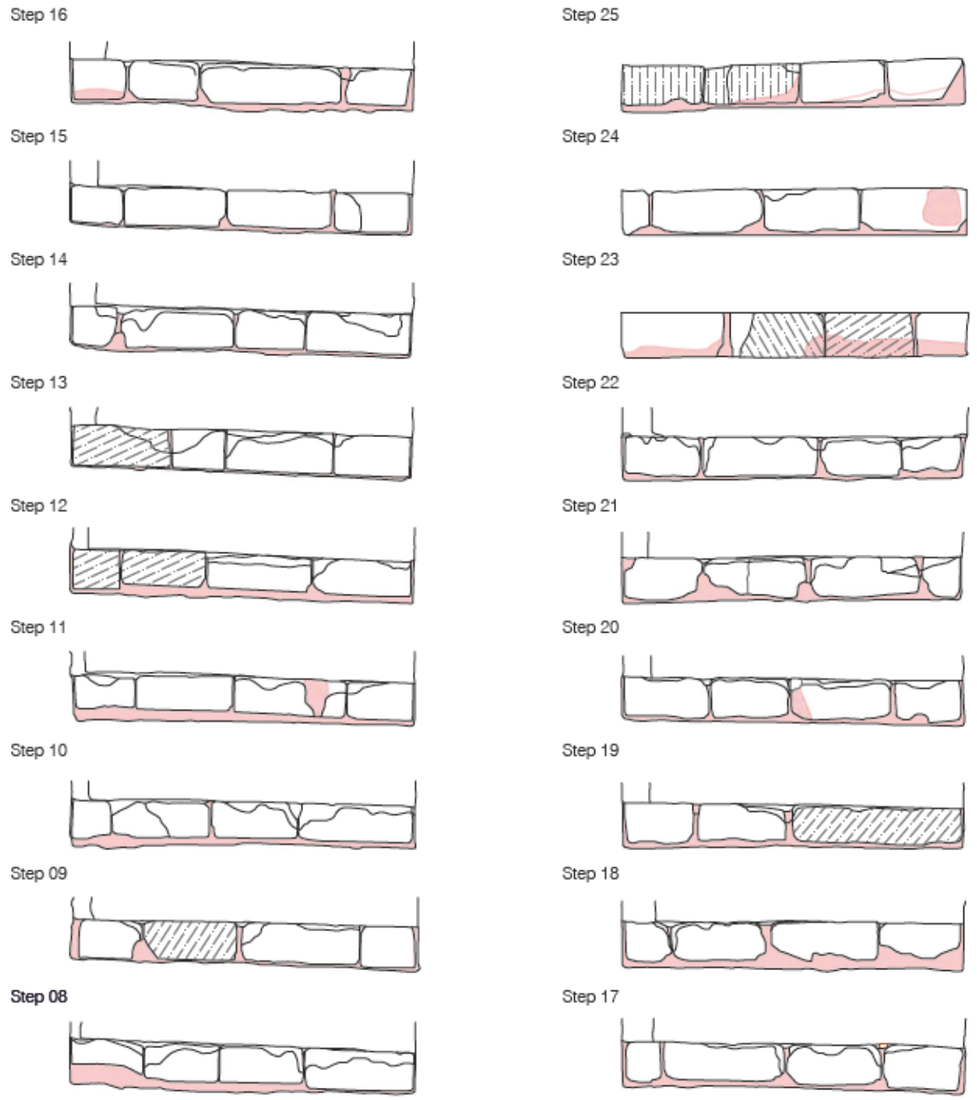
Figure 23
Plan and Elevations of Steps 8 to 25: Stone Types
with inset showing location of stairs
1:25 at A3

Mortar Type 1: Primary Medieval shell mortar
Mortar Type 4: 20th century Roman cement hard, dark grey repair mortar
Roman Tile
Carbonised Wood Impression
Tool Marks
Wood

Mortar sample
CBM sample







0 1 3 Feet
0 0.5 1 Metres

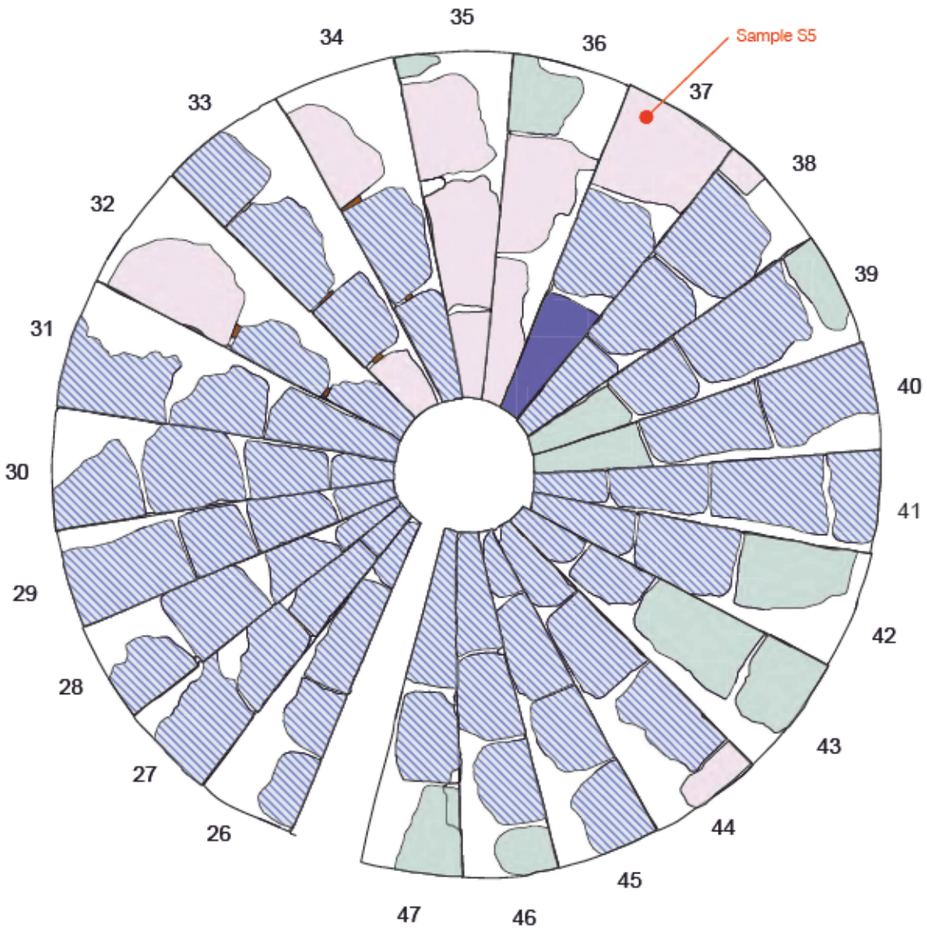
05/06/18 MR

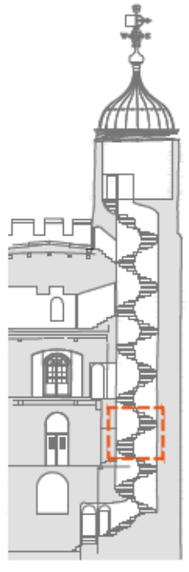
Figure 24
Plan and Elevations of Steps 8 to 25: Mortar Types
with inset showing location of stairs
1:25 at A3

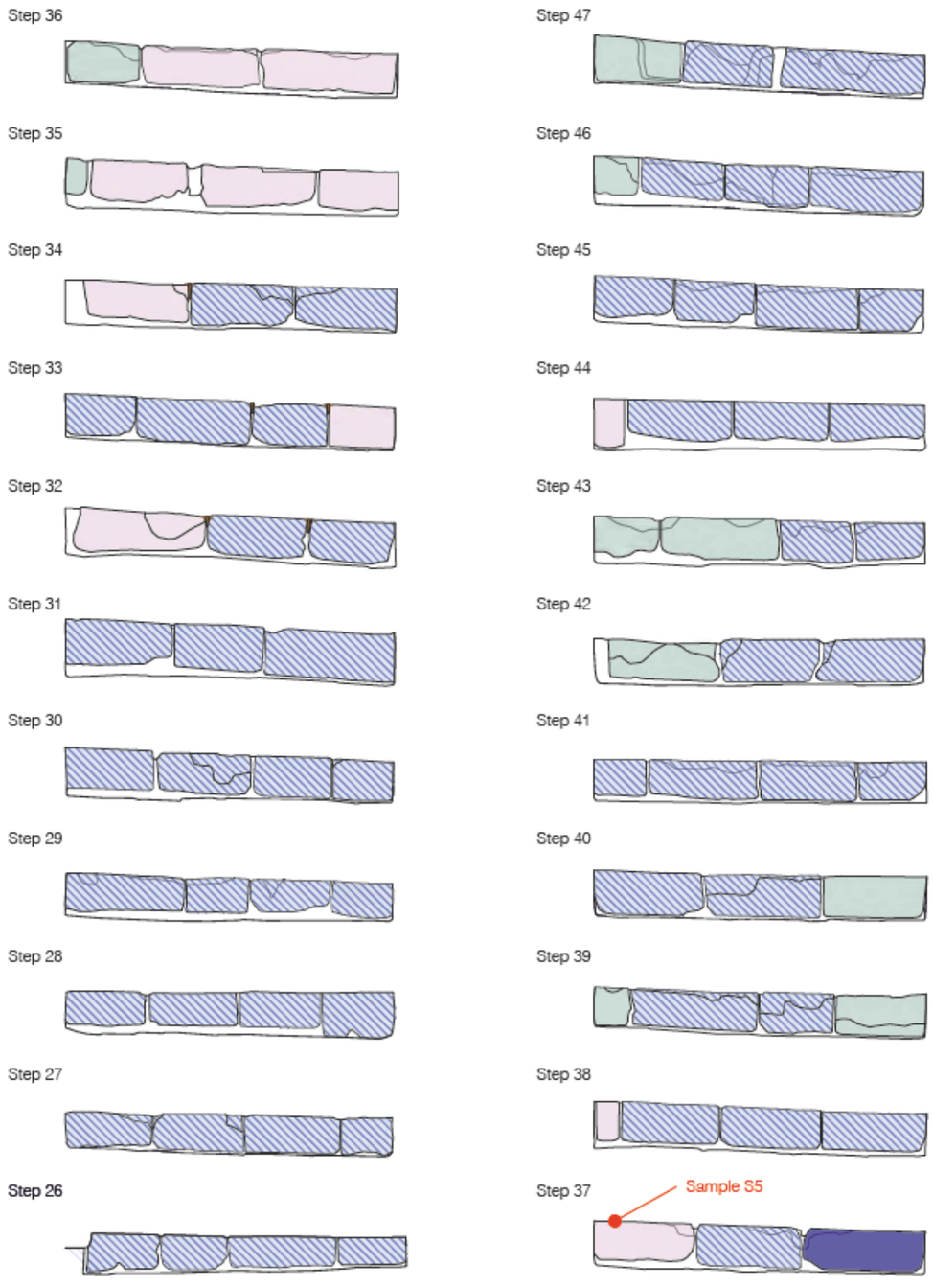
Chalk
Malmstone
Quarrstone
Reigate stone
Wood

Stone sample

N





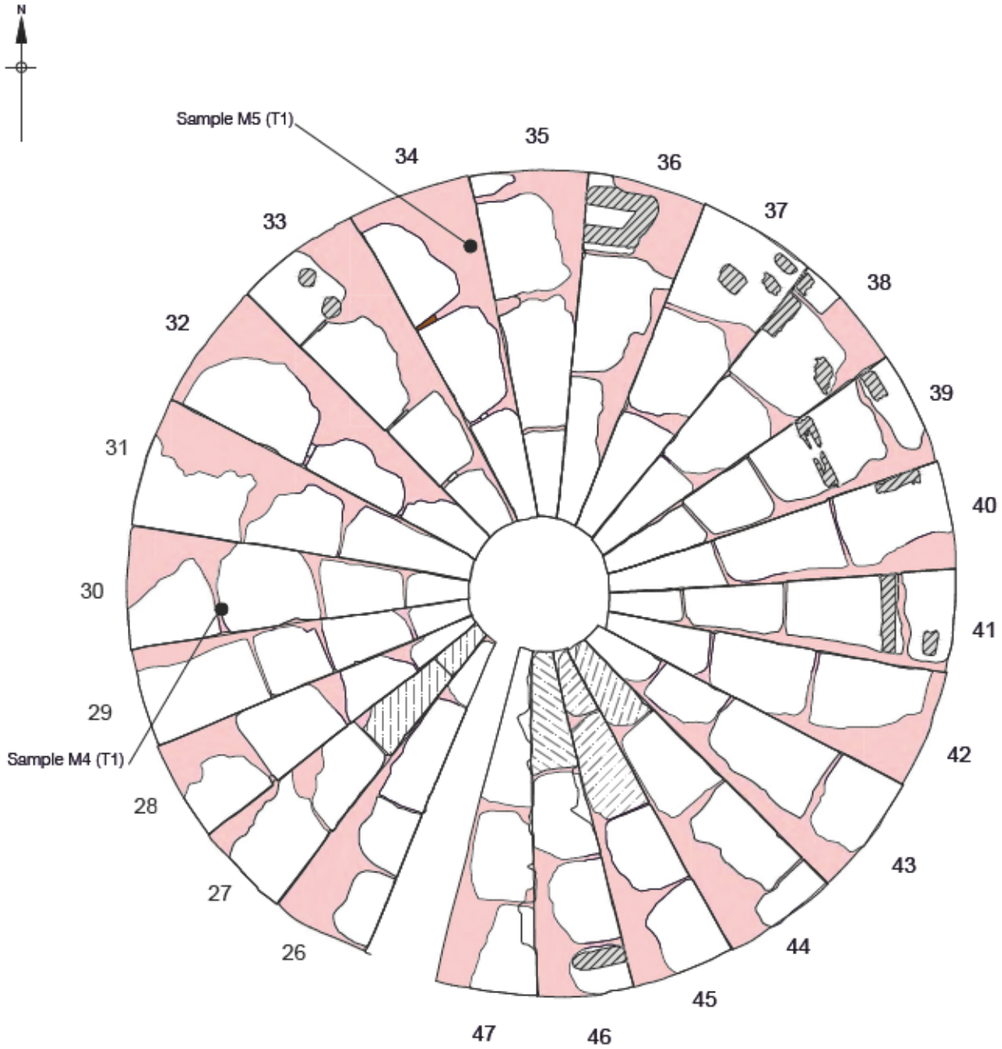


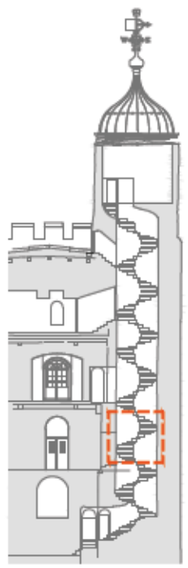
0 1 3 Feet
0 0.5 1 Metres

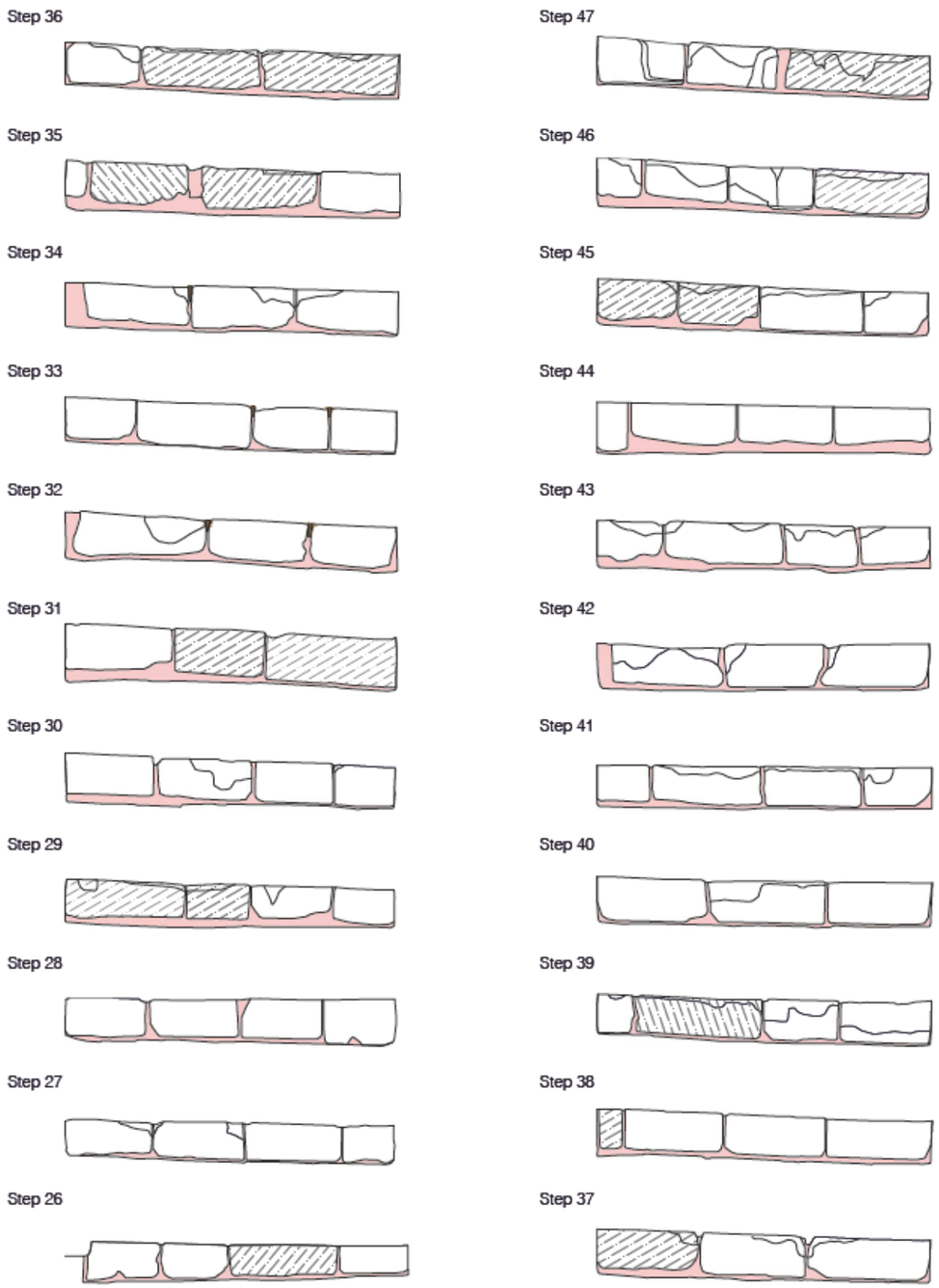
05/06/18 MR & 09/07/18 MS

Figure 25
Plan and Elevations of Steps 26 to 47: Stone Types
with inset showing location of stairs
1:25 at A3

Mortar Type 1: Primary Medieval shell mortar
Tool Marks
Carbonised Wood Impression
Wood
Mortar sample







0 1 3 Feet
0 0.5 1 Metres

05/06/18 MR & 10/07/18 MS

Figure 26
Plan and Elevations of Steps 26 to 47: Mortar Types
with inset showing location of stairs
1:25 at A3

Malmstone
Wood

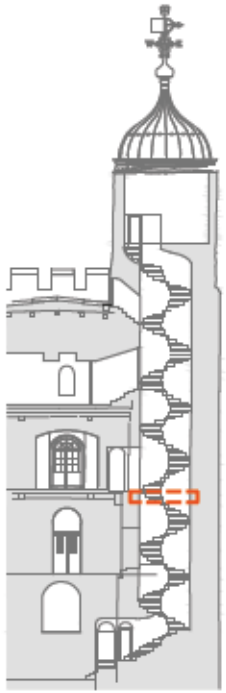
N

51 /
LANDING 5

50

49

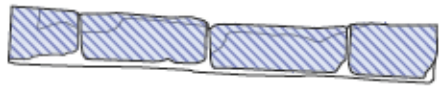
48



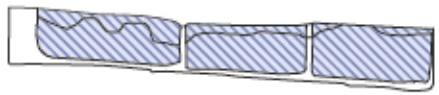
Step 51

Step 50

Step 49



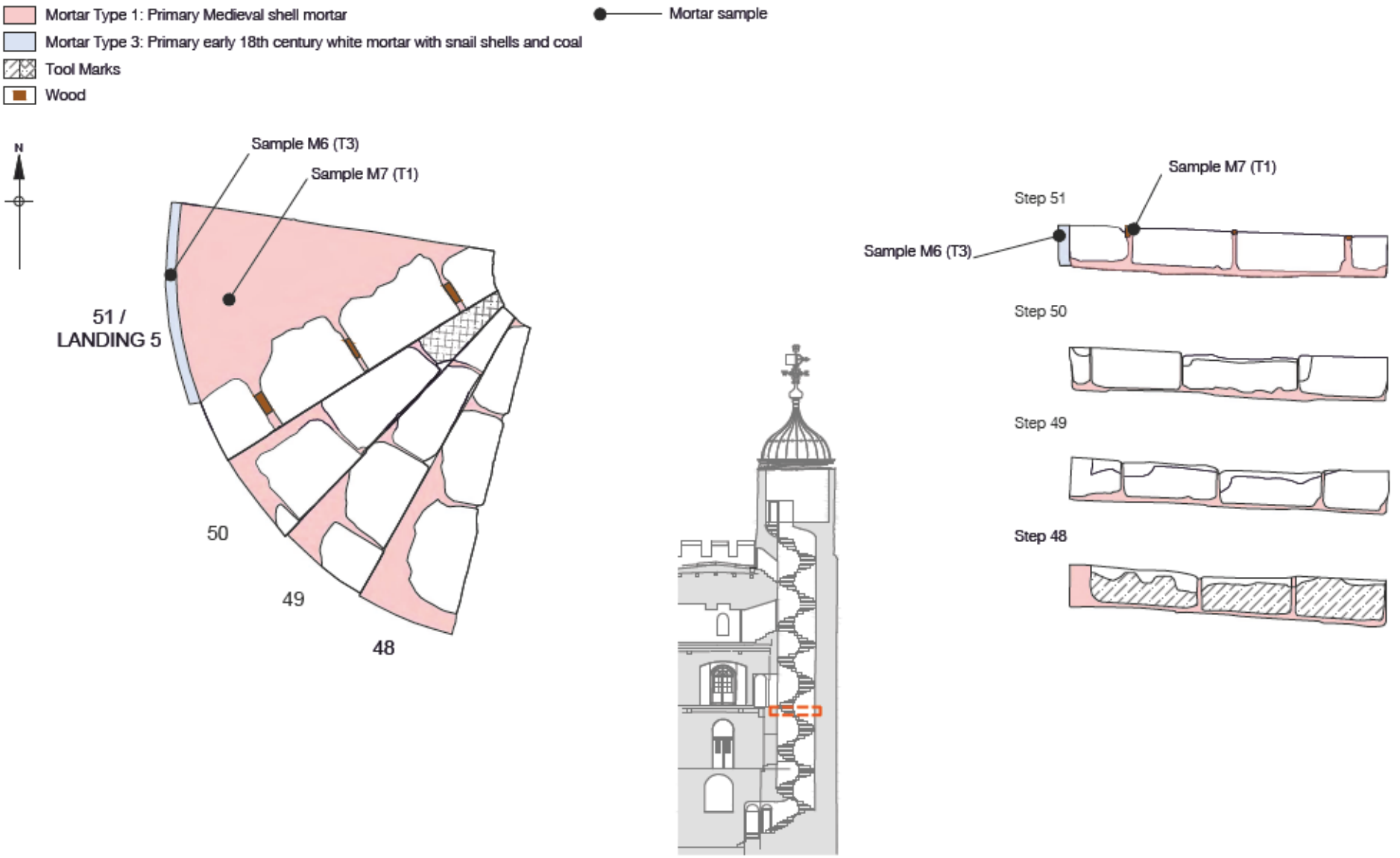
Step 48



0 1 3 Feet
0 0.5 1 Metres

05/06/18 MR & 10/07/18 MS

Figure 27
Plan and Elevations of Steps 48 to 51: Stone Types
with inset showing location of stairs
1:25 at A4



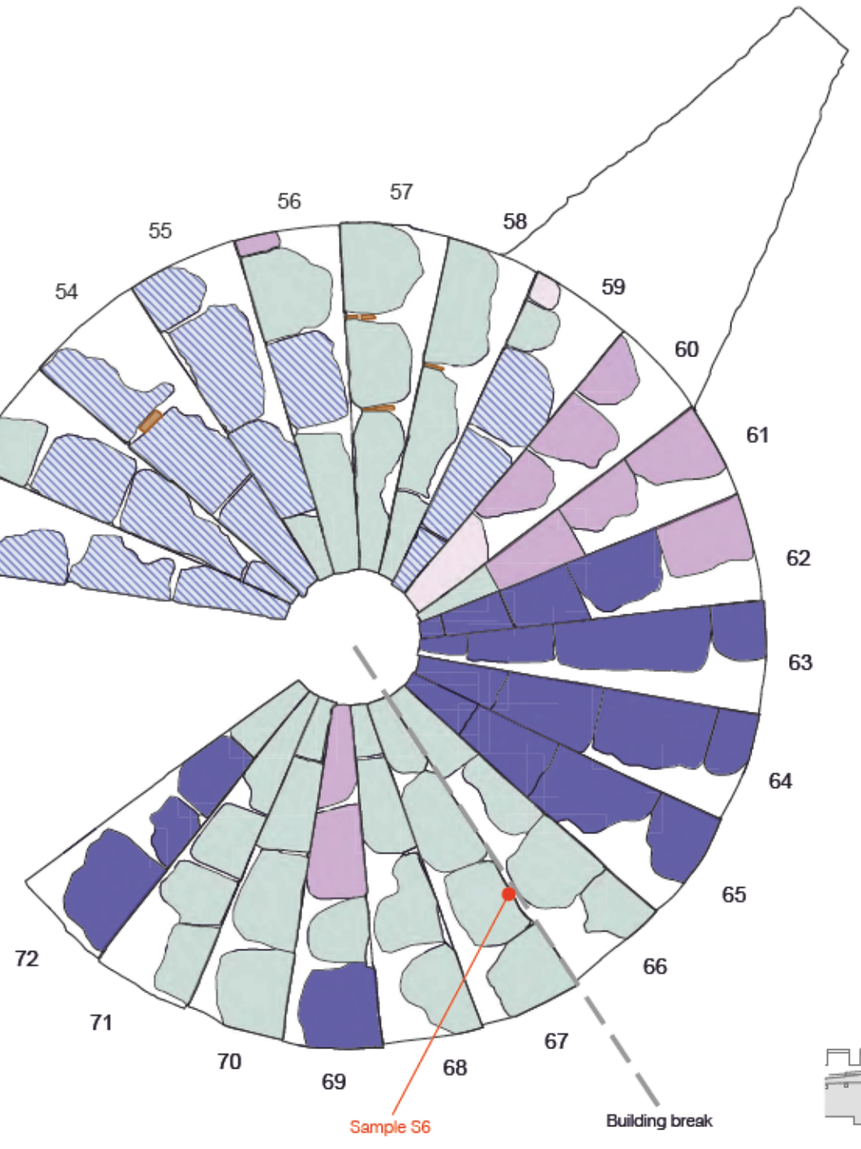
05/06/18 MR & 11/07/18 MS

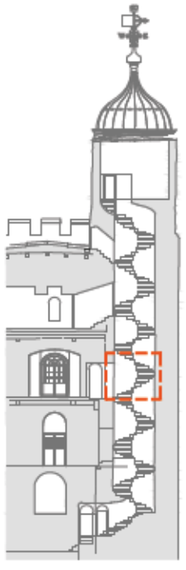
Figure 28
Plan and Elevations of Steps 48 to 51: Mortar Types
with inset showing location of stairs
1:25 at A4

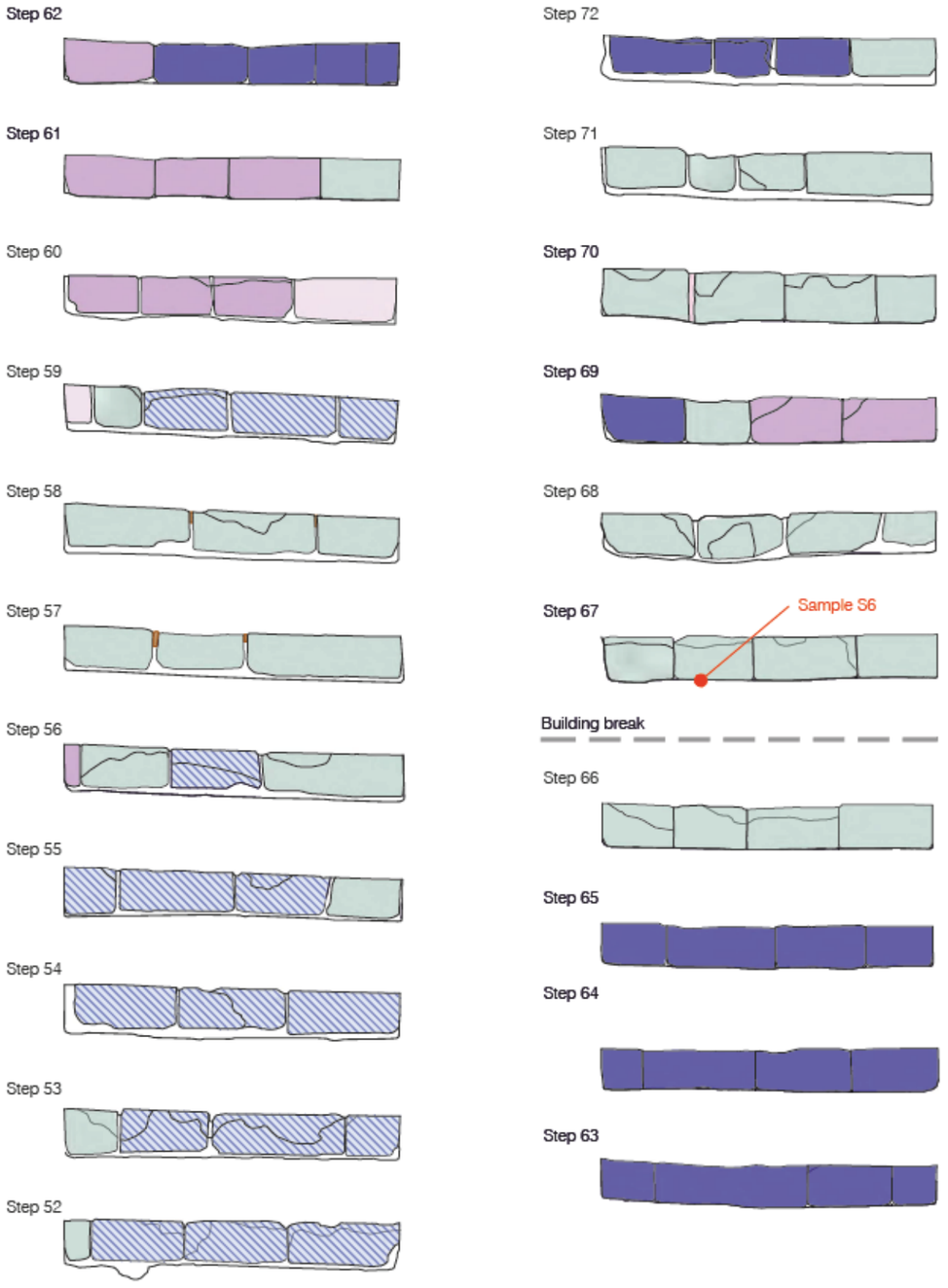
Caen stone
Chalk
Malmstone
Quarrstone
Reigate stone
Wood

Stone sample

N







0 1 3 Feet
0 0.5 1 Metres

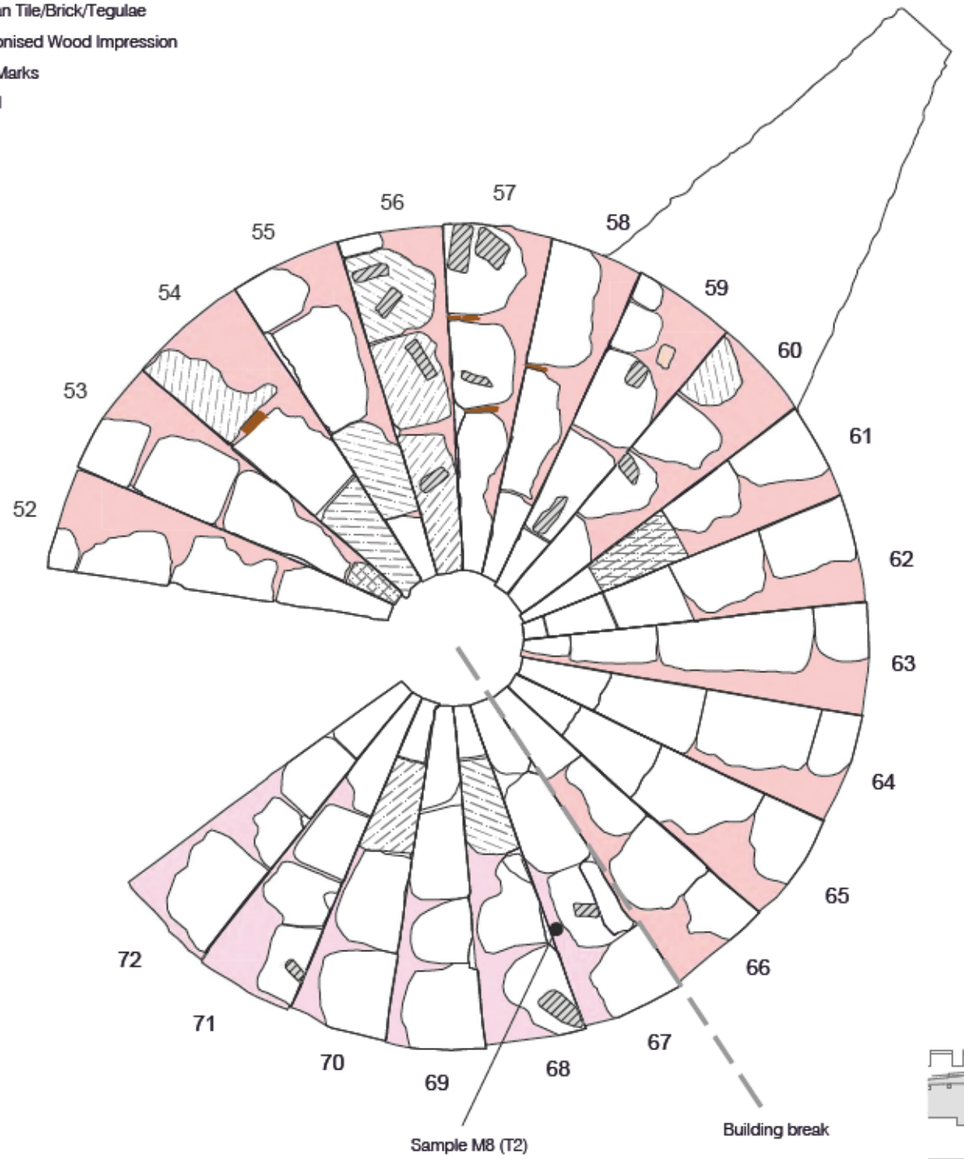
05/06/18 MR & 11/07/18 MS

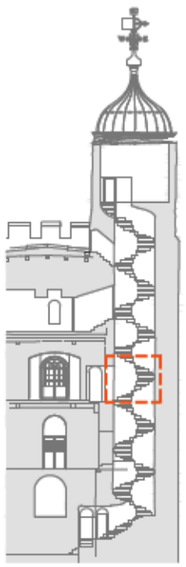
Figure 29
Plan and Elevations of Steps 52 to 72: Stone Types
with inset showing location of stairs
1:25 at A3

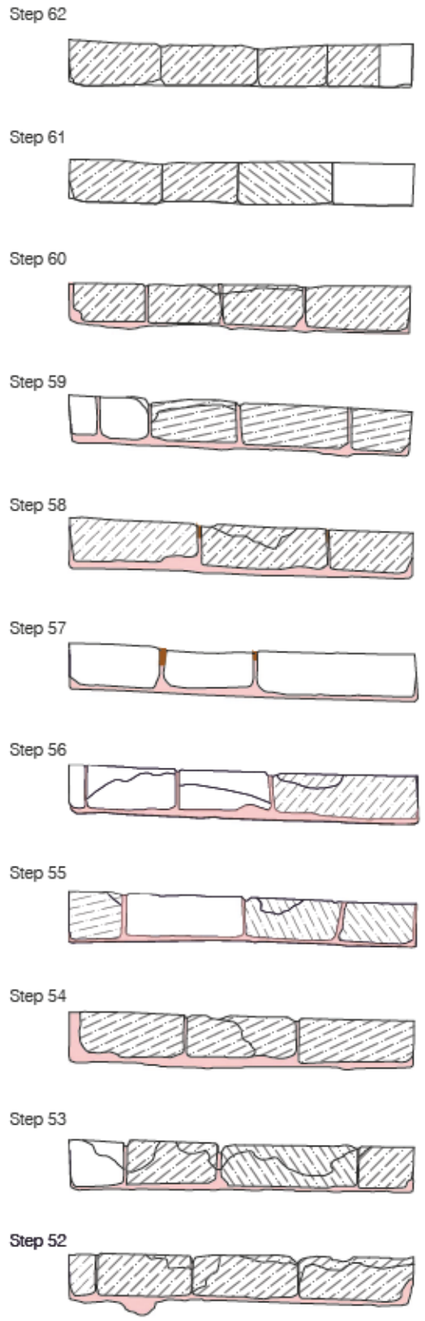
Mortar Type 1: Primary Medieval shell mortar
Mortar Type 2: Primary Medieval chalk and flint mortar
Roman Tile/Brick/Tegulae
Carbonised Wood Impression
Tool Marks
Wood

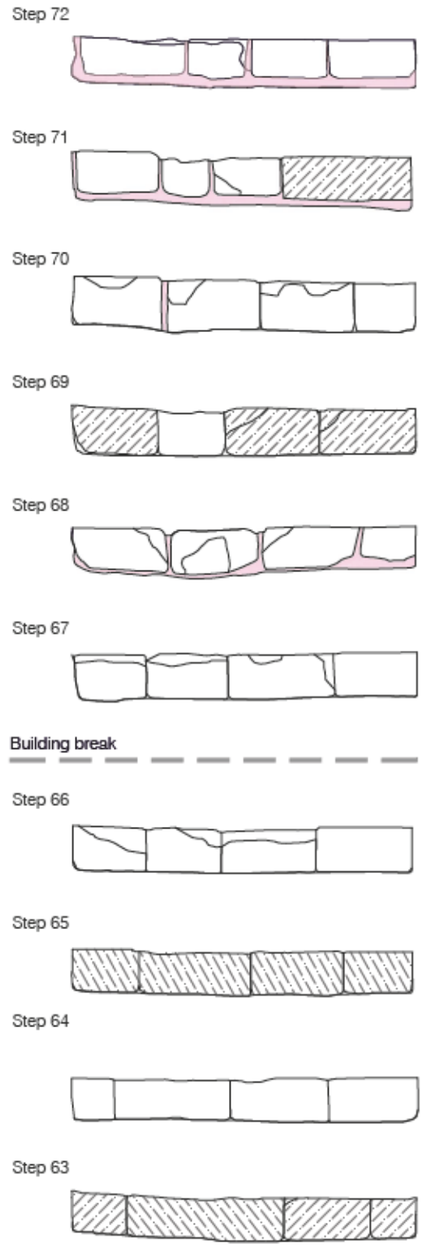
Mortar sample

N





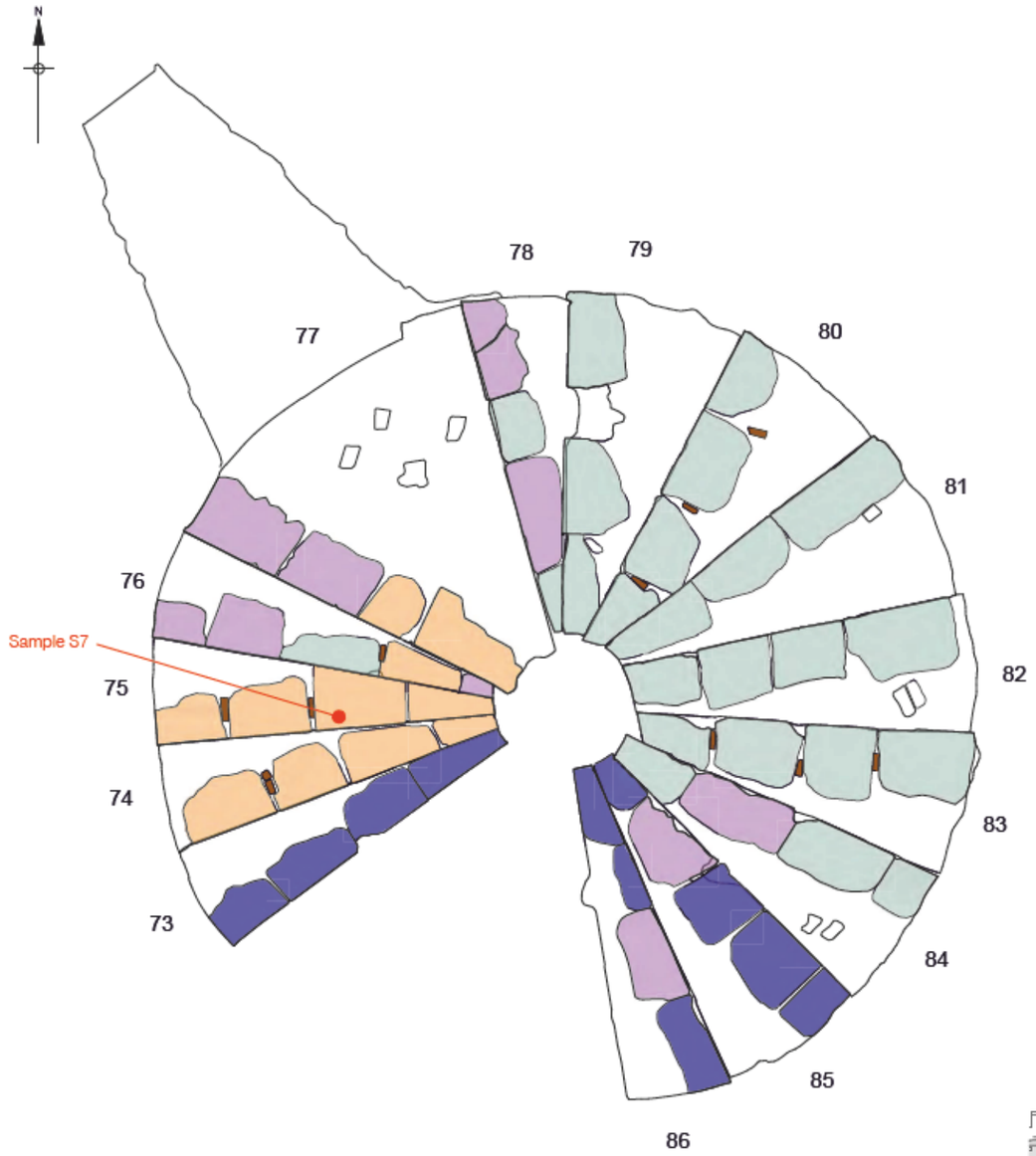


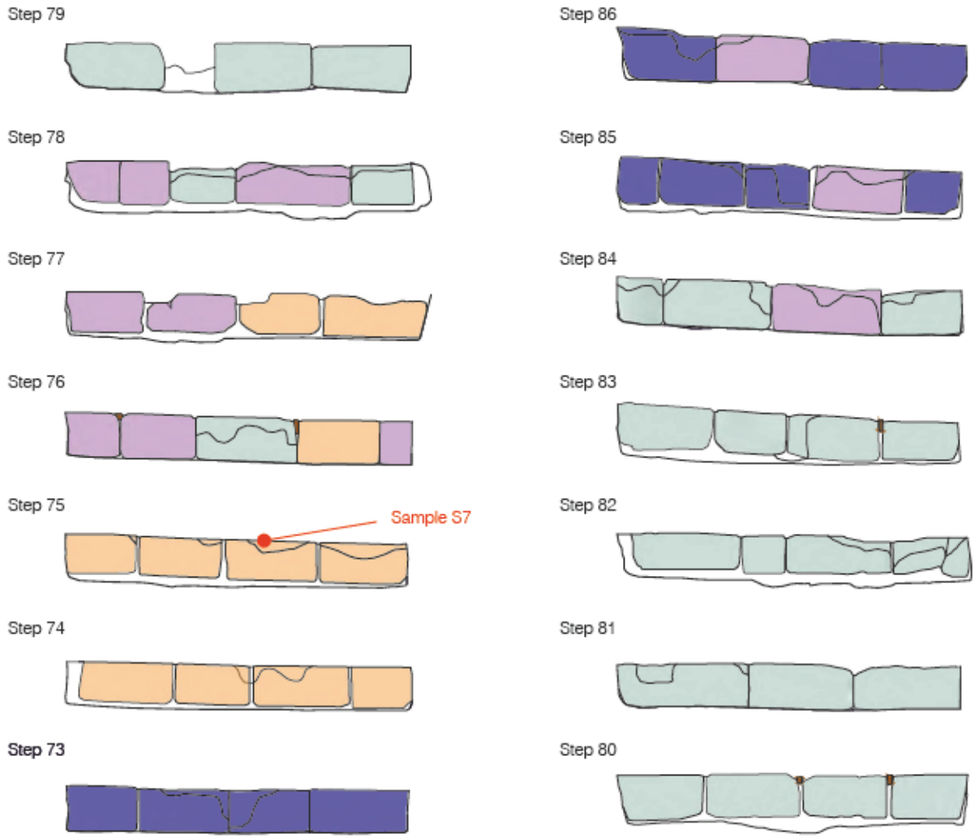


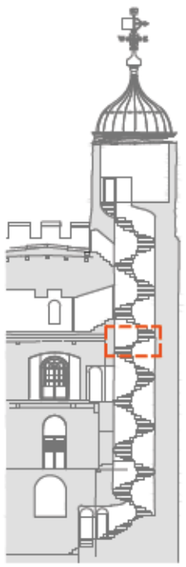
0 1 3 Feet
0 0.5 1 Metres

05/06/18 MR & 12/07/18 MS

Figure 30
Plan and Elevations of Steps 52 to 72: Mortar Types
with inset showing location of stairs
1:25 at A3





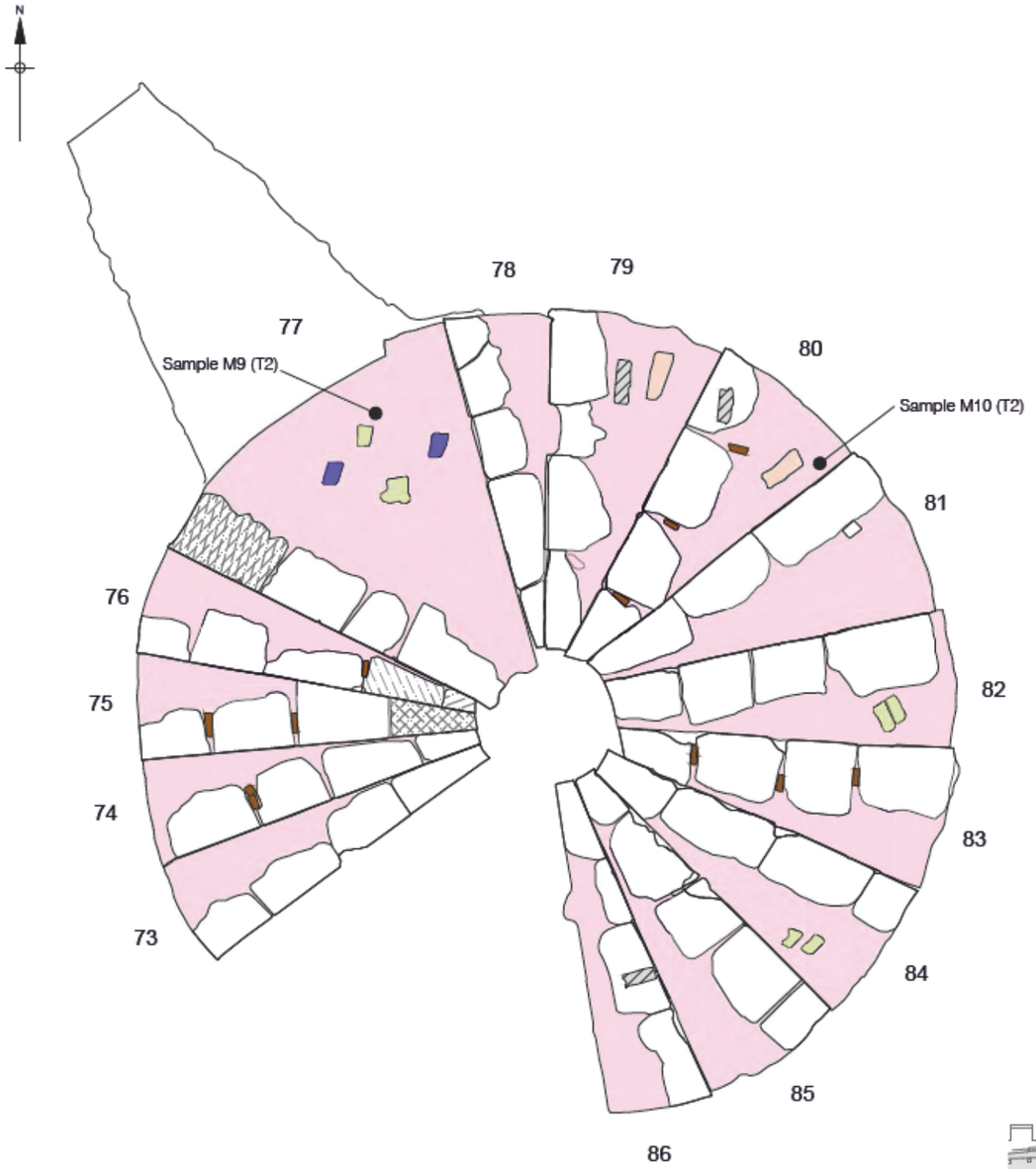


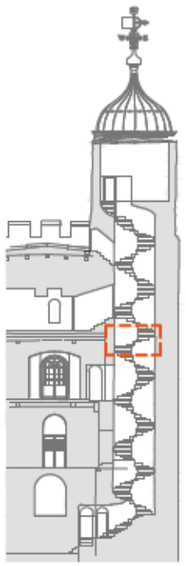
Bembridge Limestone
Caen stone
Quarrstone
Reigate stone
Wood
Stone sample

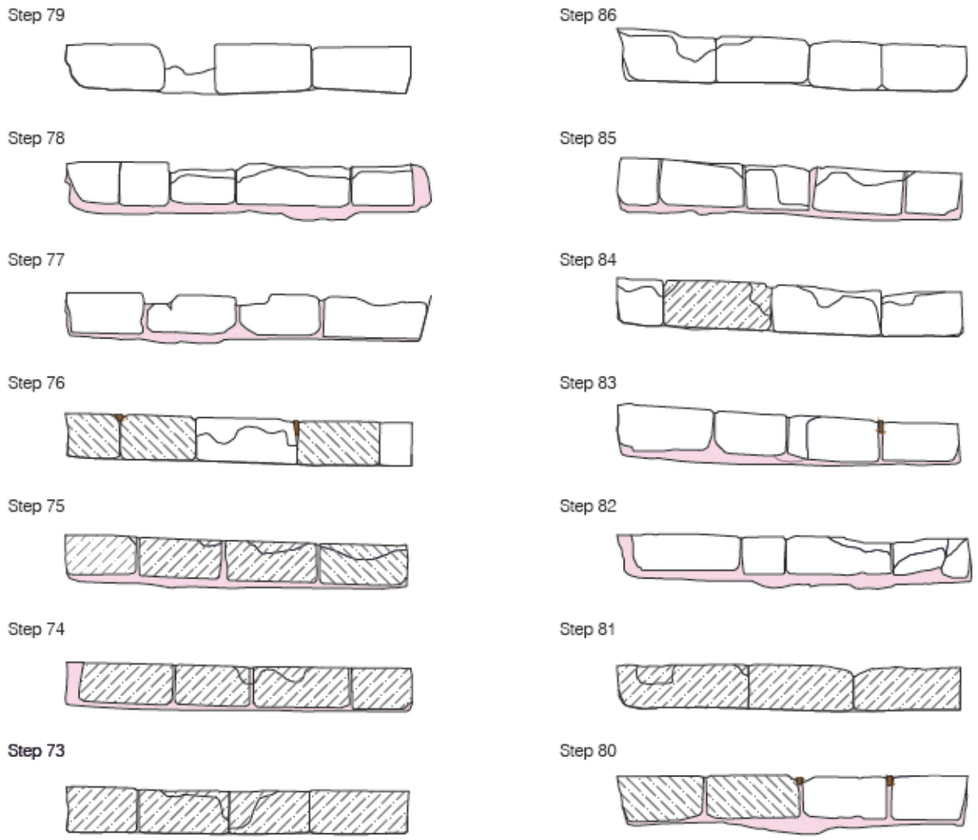
0 1 3 Feet
0 0.5 1 Metres

05/06/18 MR & 16/07/18 MS

Figure 31
Plan and Elevations of Steps 73 to 86: Stone Types
with inset showing location of stairs
1:25 at A3







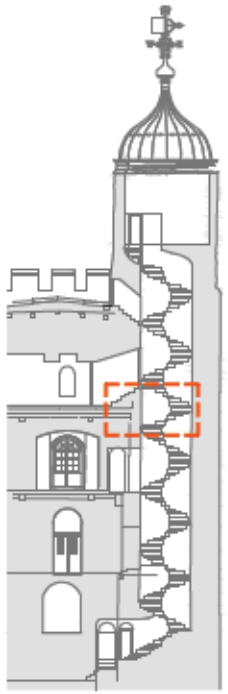
Mortar Type 2: Primary Medieval chalk and flint mortar
Roman Tile/Brick/Tegulae
Quarrstone
Kentish Ragstone
Carbonised Wood Impression
Tool Marks
Wood

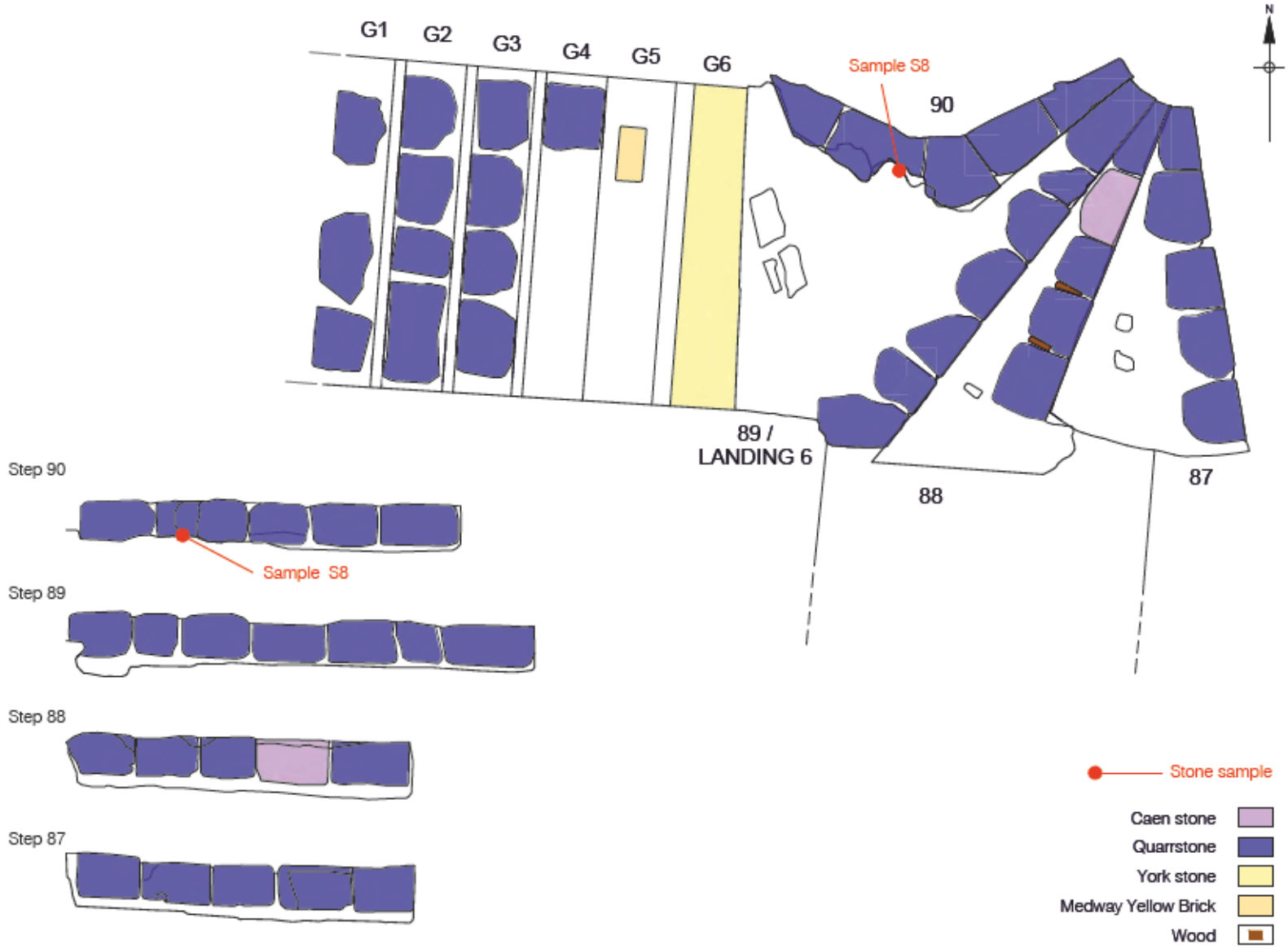
Mortar sample

0 1 3 Feet
0 0.5 1 Metres

05/06/18 MR & 16/07/18 MS

Figure 32
Plan and Elevations of Steps 73 to 86: Mortar Types
with inset showing location of stairs
1:25 at A3

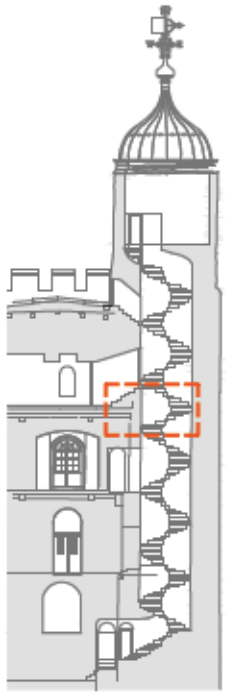


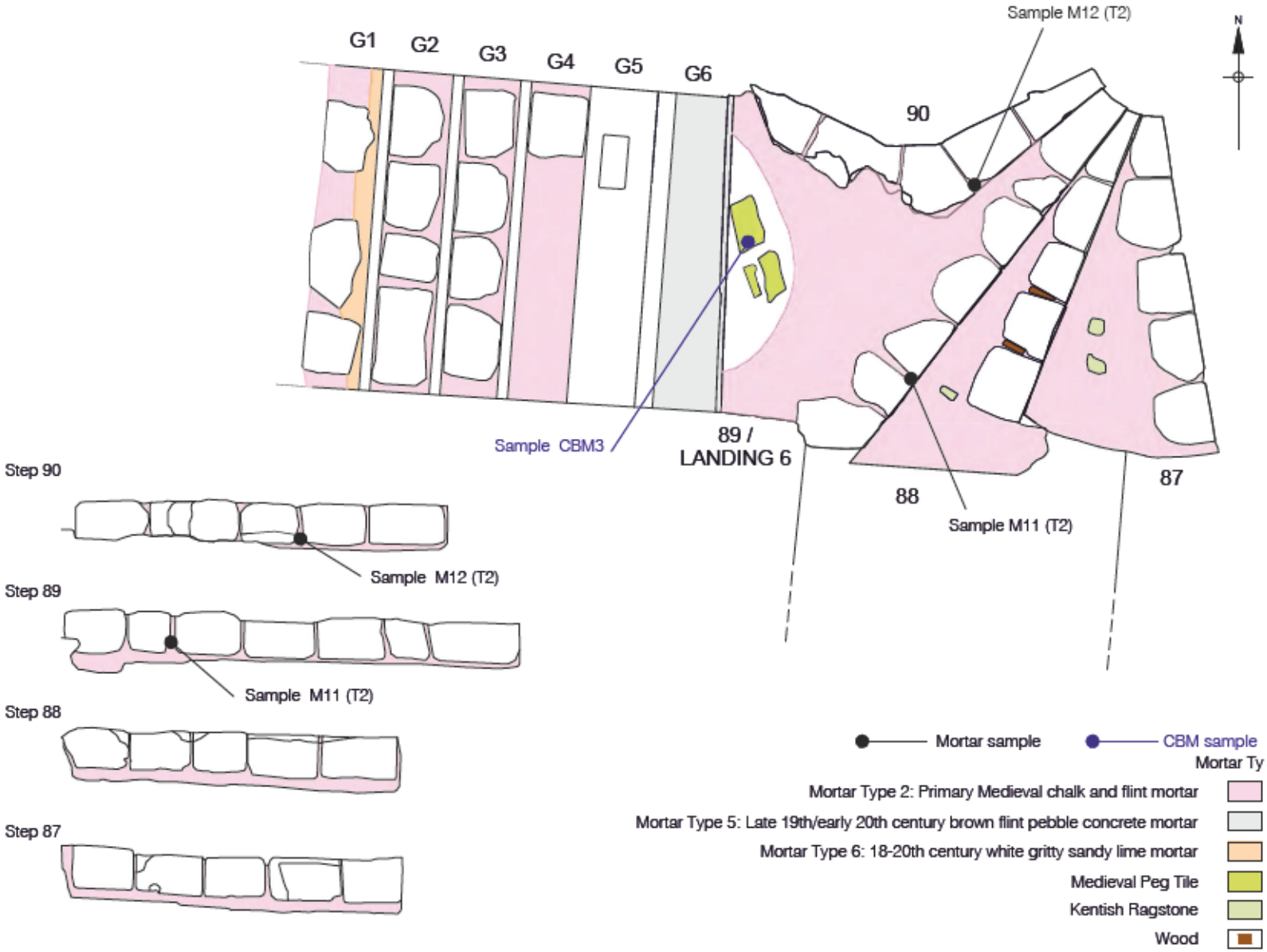


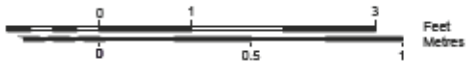
0 1 3 Feet
0 0.5 1 Metres

05/06/18 MR & 17/07/18 MS

Figure 33
Plan and Elevations of Steps 87 to 90 and Steps G1 to G6: Stone Types
with inset showing location of stairs
1:25 at A4

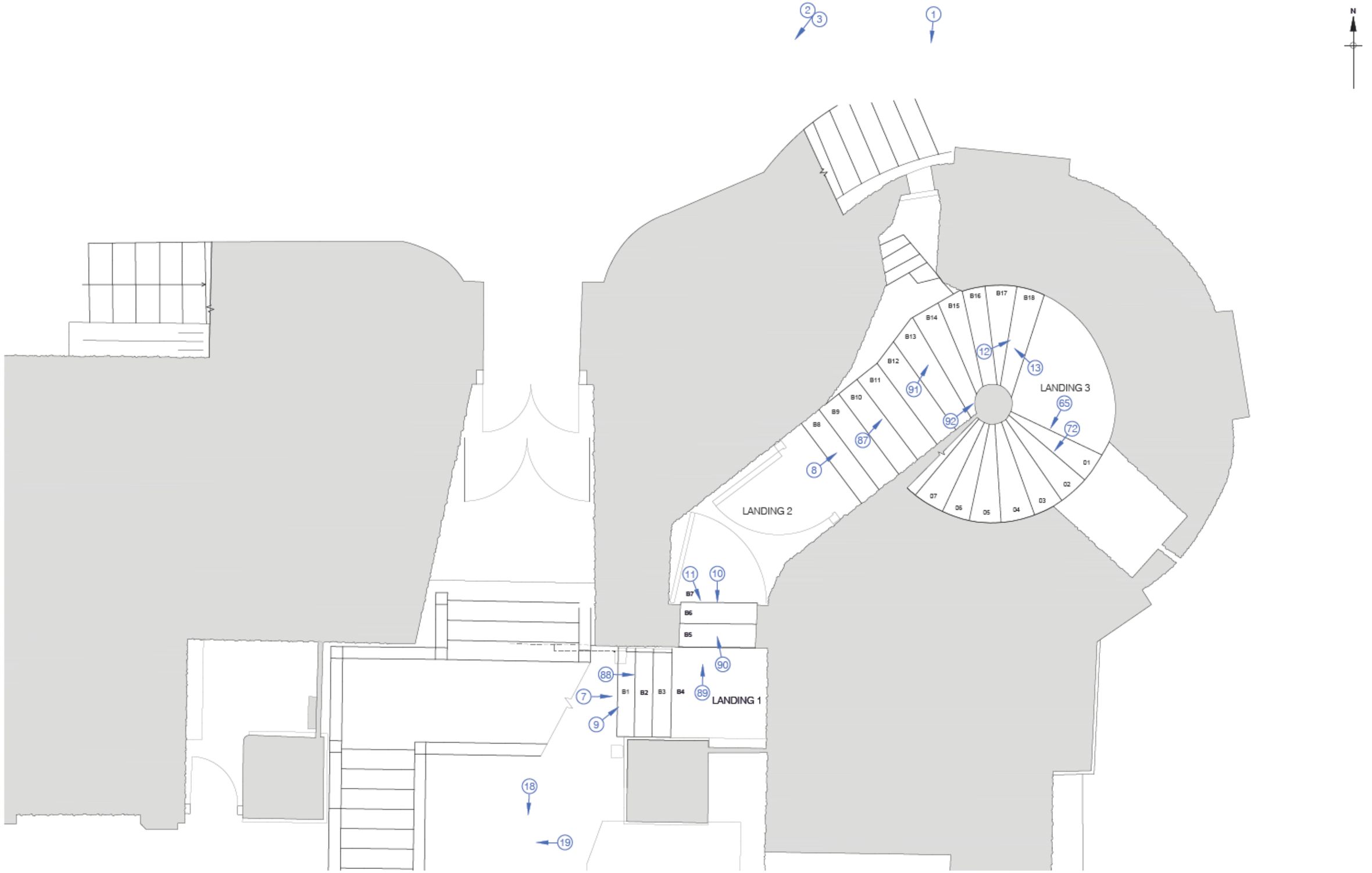






05/06/18 MR & 17/07/18 MS

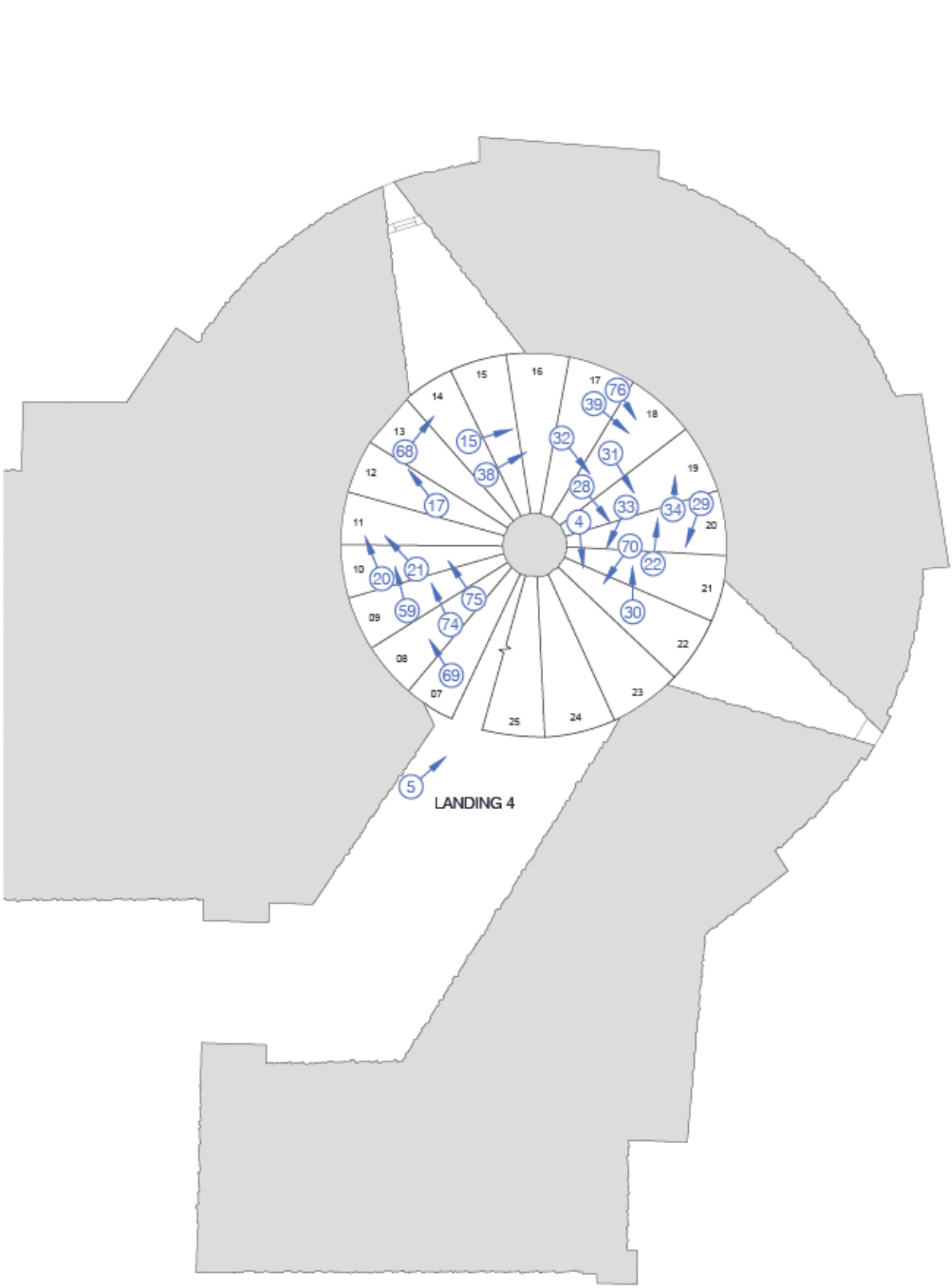
Figure 34
Plan and Elevations of Steps 87 to 90 and Steps G1 to G6: Mortar Types
with inset showing location of stairs
1:25 at A4



0 2 6 Feet
0 1 2 Metres

05/06/18 MR & 31/07/18 MS

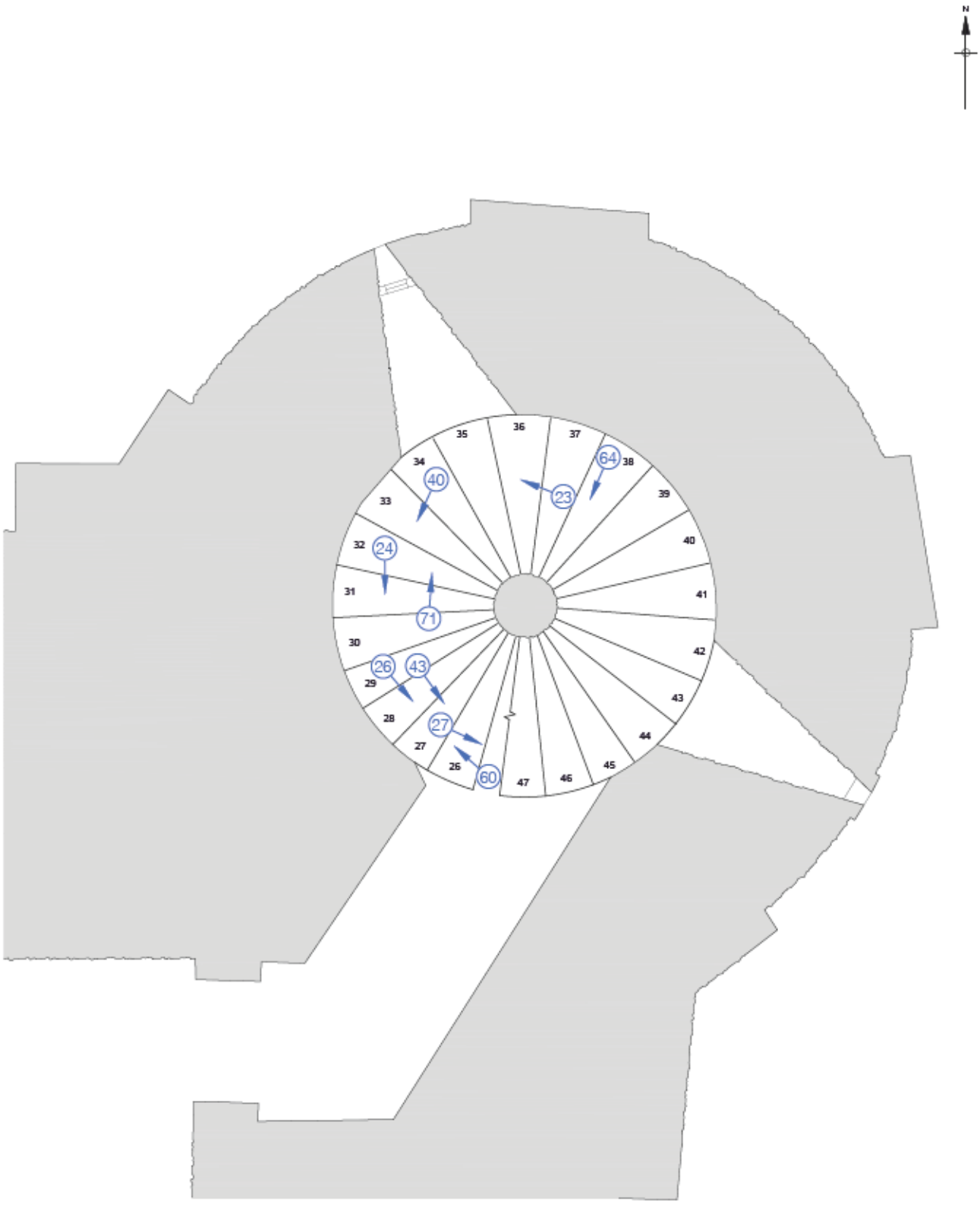
Figure 35
Plate locations: Basement and Stairs 1 to 7
1:50 at A3



0 2 6 Feet
0 1 2 Metres

05/06/18 MR & 31/07/18 MS

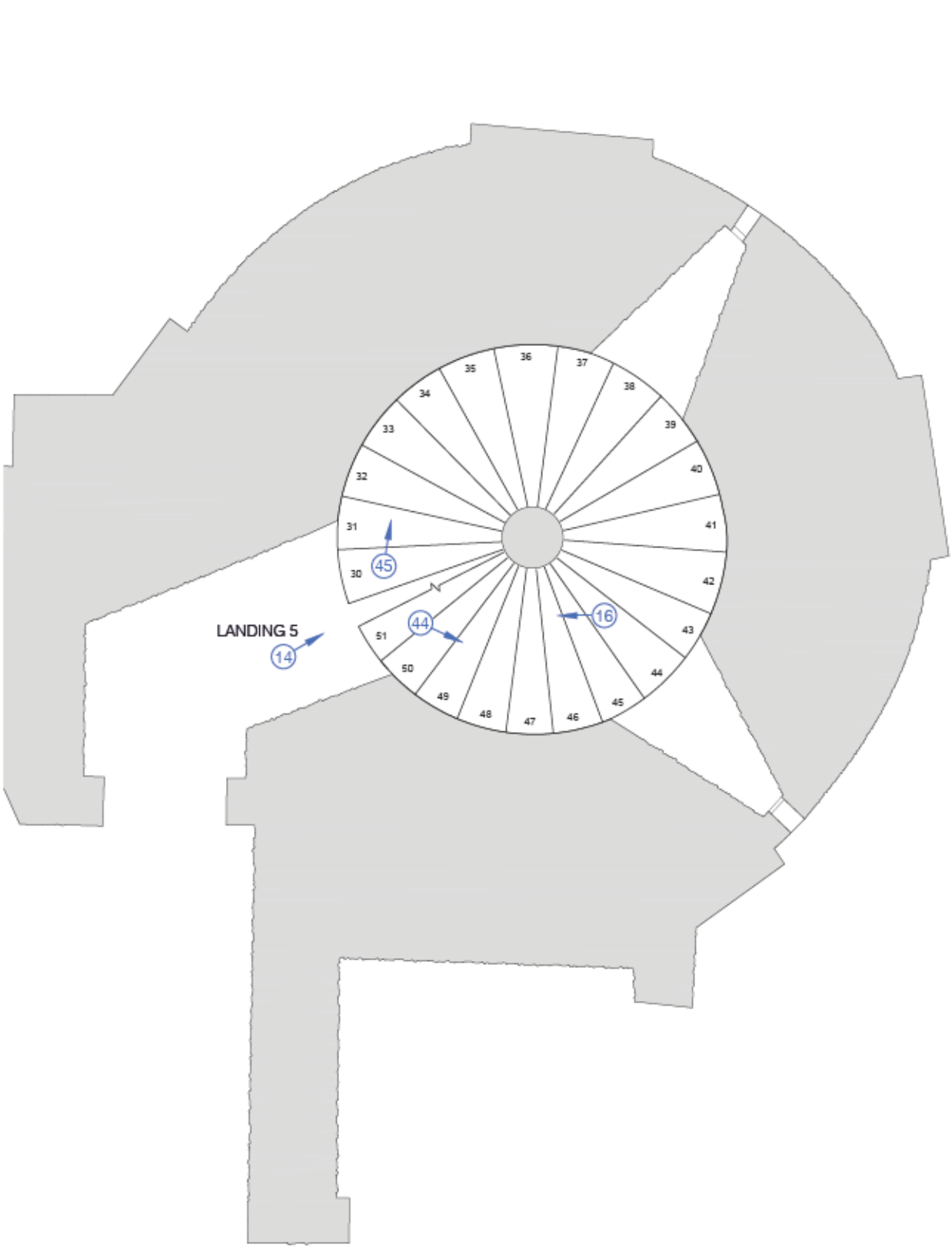
Figure 36
Plate locations: Stairs 8 to 25
1:50 at A4



0 2 6 Feet
0 1 2 Metres

05/06/18 MR & 31/07/18 MS

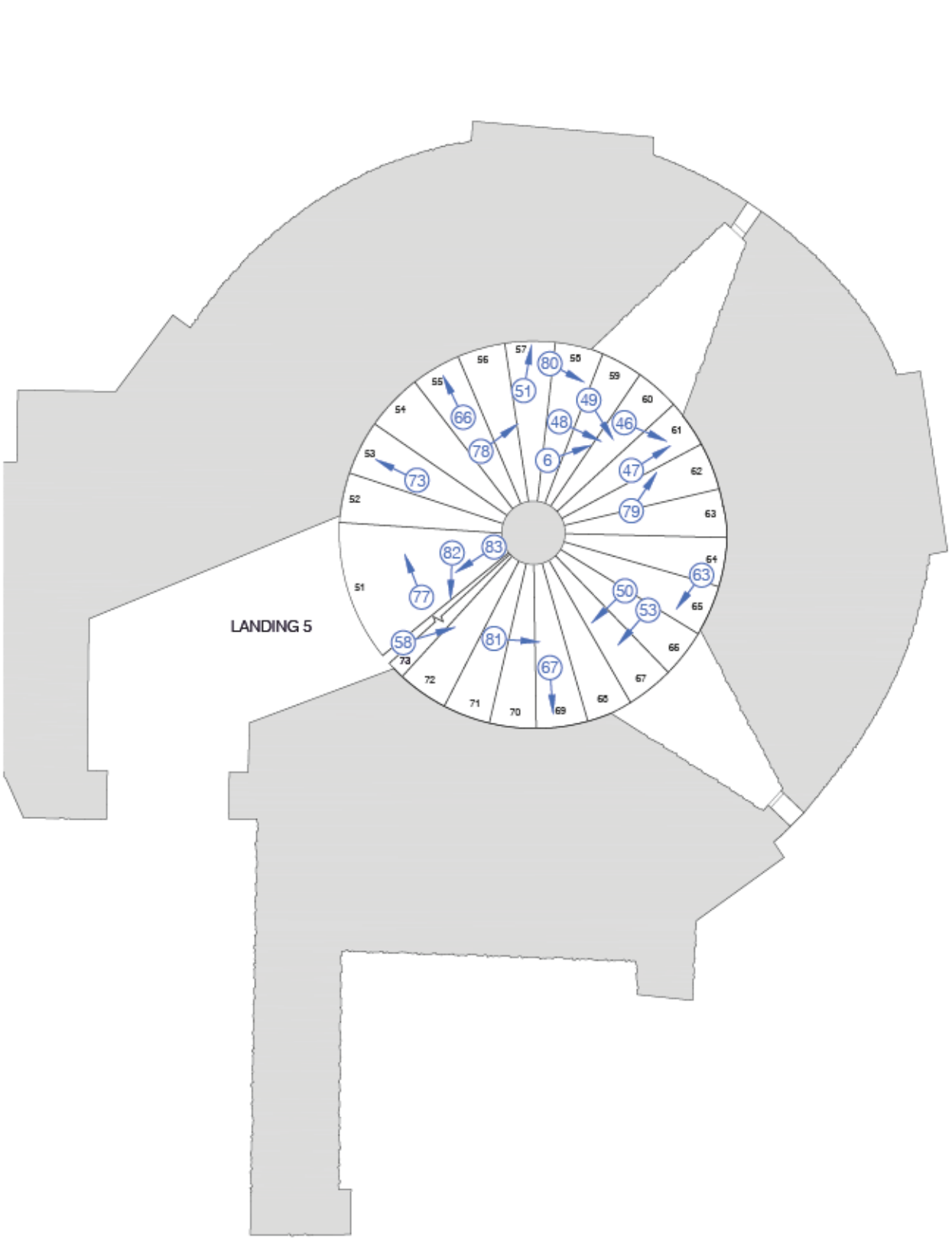
Figure 37
Plate locations: Stairs 26 to 47
1:50 at A4



0 2 6 Feet
0 1 2 Metres

05/06/18 MR & 31/07/18 MS

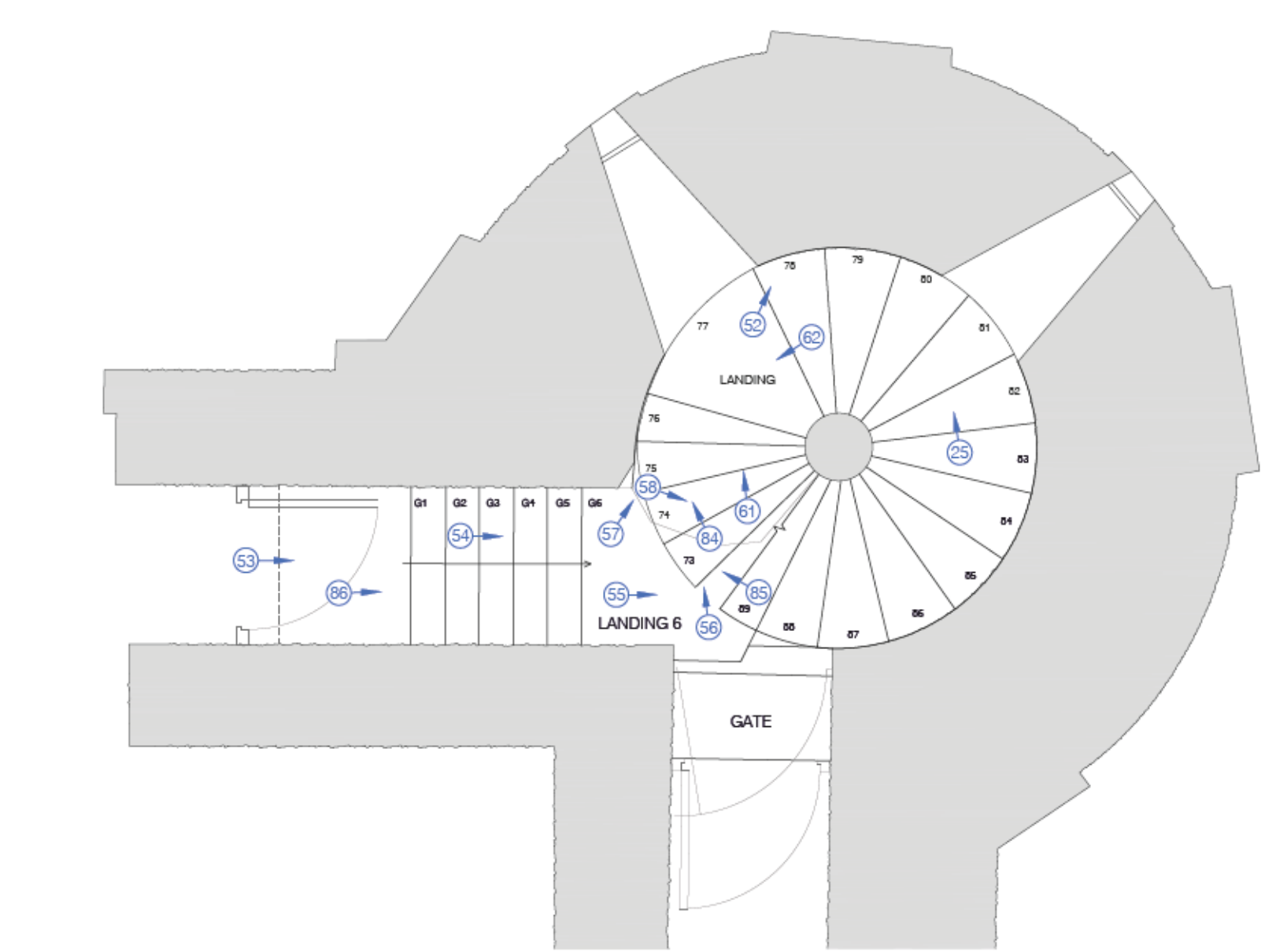
Figure 38
Plate locations: Stairs 48 to 51
1:50 at A4



0 2 6 Feet
0 1 2 Metres

05/06/18 MR & 31/07/18 MS

Figure 39
Plate locations: 51 to 72
1:50 at A4



05/06/18 MR & 31/07/18 MS

Figure 40
Plate locations: 73 to 89
1:50 at A4

Plate 1: The Flamsteed Turret, looking south

Plate 2: Construction of scaffolded staircase to serve as the temporary exit for the White Tower during works, looking south

Plate 3: Temporary scaffolded staircase from the White Tower nearing completion, looking south

Plate 4: Installation of dust barrier above Step 23 prior to commencement of work

Plate 5: Dust barrier above Step 23

Plate 6: Photographic survey of the remains found below the modern timber covers (Step 60) ©HRP (Provided by Historic Royal Palaces)

Plate 7: Steps B1 to B4 prior to removal, looking east ©Robin Foster (Provided by Historic Royal Palaces)

Plate 8: Stone steps (B9 up to B18) ©Robin Foster (Provided by Historic Royal Palaces)

Plate 9: Stairs B1 up to B4 (Landing 1) during removal, looking east

Plate 10: Removal of Step B4 (Landing 1), looking south

Plate 11: Void beneath Step B4 (Landing 1), looking south-east

Plate 12: Cleaning and removal of grit tread on stairs B1-B19 (B18 and B19)

Plate 13: Kevin Hayward inspecting new stone indents in Steps B12 to B19

Plate 14: Flamsteed Turret stair treads prior to the removal (Step 58 down to 43) ©Robin Foster (Provided by Historic Royal Palaces)

Plate 15: Flamsteed Turret stair risers prior to the removal (Step 15 up to 20)

Plate 16: Softwood wedges used to provide tension to timber covers prior to removal (Step 45 up to 50)

Plate 17: Softwood wedges showing some signs of damage to the walls of the Flamsteed Turret (Steps 12 and 13)

Plate 18: Upper side of removed tread and riser (Step 21)

Plate 19: Soffit (underside) of removed tread and riser (Step 21)

Plate 20: Damaged caused by wedges on the walls of the turret (Step 11)

Plate 21: Damage caused to the newel by a wedge (Step 11)

Plate 22: Evidence of re-use of timbers with empty screw holes (Step 20)

Plate 23: Gap between timber and stone riser at Step 35

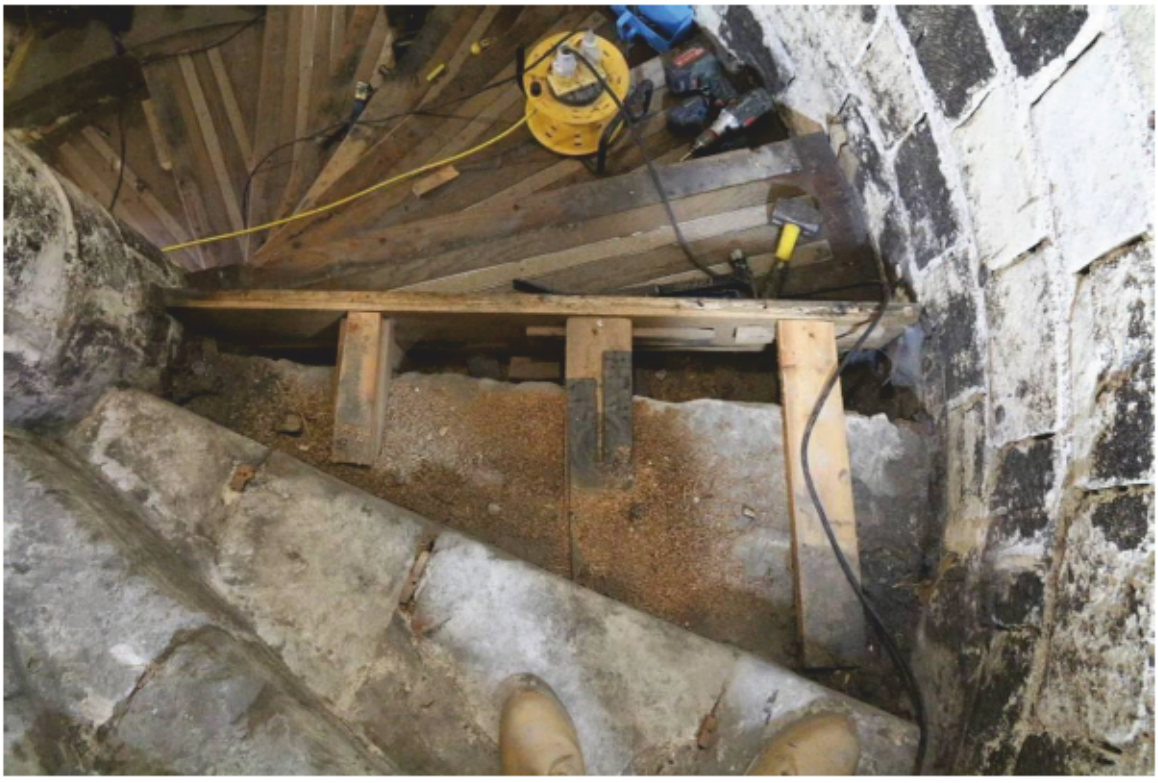


Plate 24: Modern timber covers screwed into historic timber piles (Step 31)

Plate 25: Rubber and timber cut-offs below timber treads (Step 82)

Plate 26: Waste timber used as a rest for the timber tread of Step 28

Plate 27: Refuse placed under the timber cover of Step 26

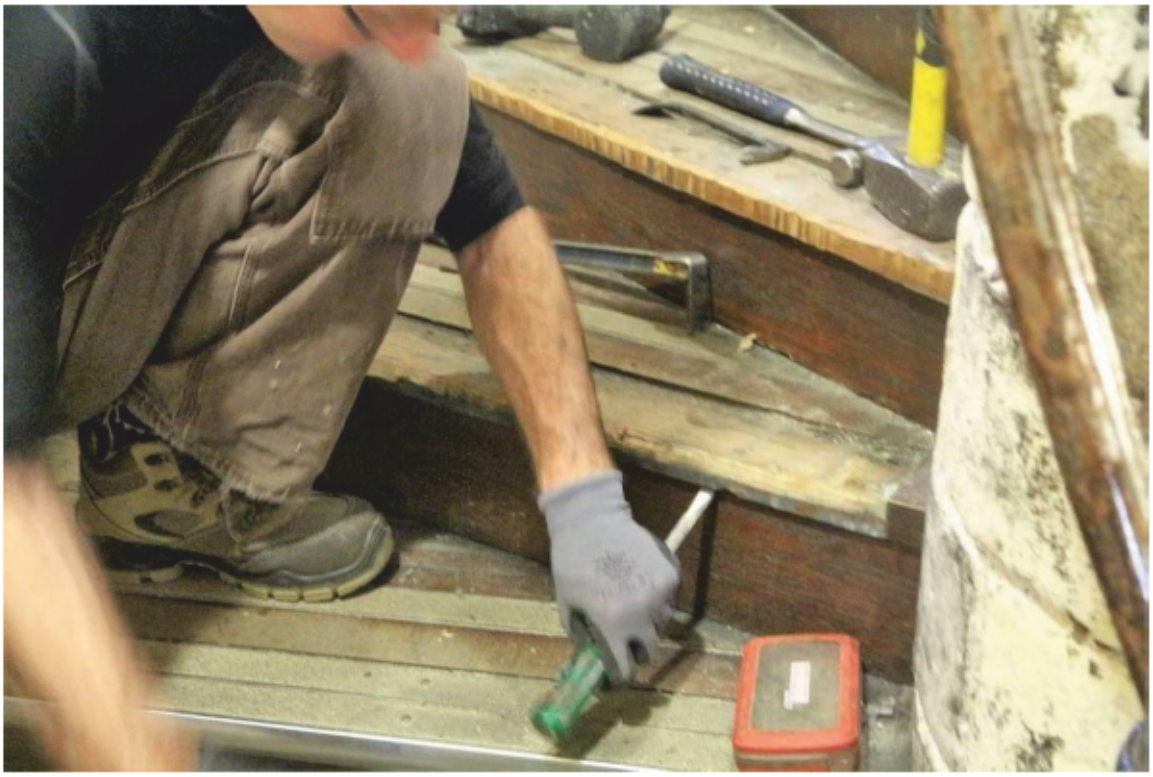


Plate 28: Removal of the first timber tread (Step 21)

Plate 29: Removal of the first tread of Step 21 showing the condition of the stone step beneath

Plate 30: Removal of the timber tread for Step 20

Pate 31: Step 20 as uncovered next to Step 21 after the removal of refuse

Plate 32: Steps 18 to 21 after the removal of the timber covers prior to cleaning

Plate 33: Late 18th/early 19th century rose head nail in a timber insert in Step 20

Plate 34: A ticket to The Tower of London dated 12 September 2001 buried in dust on the right hand side of Step 19

Plate 35: Tower of London Tickets found during the removal of the modern covers. (Top [1995] was found on Step 28) (Bottom [2001] was found on Step 19)

Plate 36: Graffiti on the soffit (underside) of timber tread for Step 16

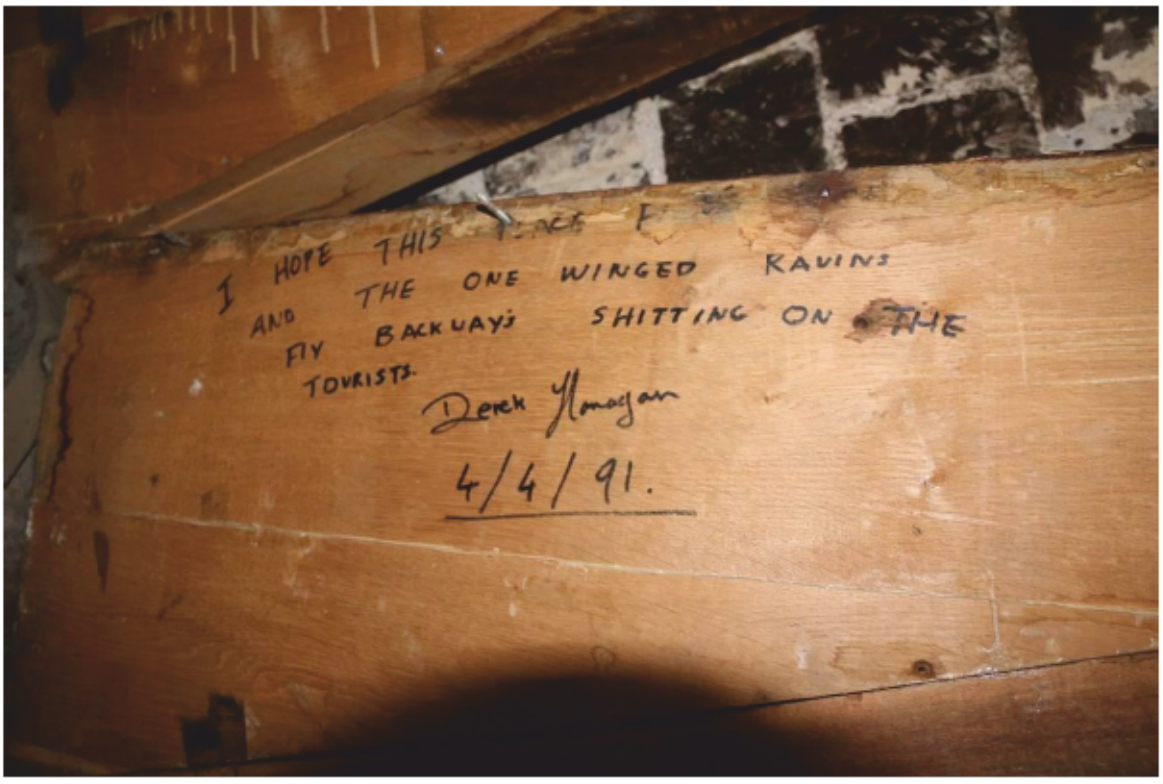


Plate 37: Graffiti on the soffit (underside) of timber tread for Step 14

Plate 38: Timber pile driven into the mortar of Step 15

Plate 39: Timber pile driven into the mortar of Step 18

Plate 40: The shilling found on Step 34 was not visible until the removal of the dust

Plate 41: Reverse side of the 1960 Shilling found on Step 34

Plate 42: Obverse side of the 1960 Shilling found on Step 34

Plate 43: Step 28, 1995 ticket can be seen on the left hand side.

Plate 44: Steps 51 to 44 use soft fawn very shelly mortar

Step 45: Steps 31 to 33 with timber inserts driven into Steps 32 and 33

Step 46: Rifle round (most likely fashion accessory) *in-situ* on Step 61 prior to removal by Tower of London staff

Step 47: Close-up of rifle round *in-situ* on Step 61 prior to removal by Tower of London staff

Plate 48: Norman axe marks made with a chisel head on Steps 59 to 62

Plate 49: Norman axe marks made with a chisel head on Step 60.

Plate 50: Step 67 marks the break in the construction of the White Tower

Plate 51: Break in construction of the Flamsteed Turret above Step 58

Plate 52: Screw in Step 78 and hammered flat by previous contractors.

Plate 53: Flamsteed Turret timber treads and risers of Steps G1 up to G6, 89 to 91 prior to removal ©Robin Foster (provided by Historic Royal Palaces)

Plate 54: Step G3 constructed from small, poorly worked blocks of Quarr stone

Plate 55: Step 98 down to 84 showing transition from Victorian (Step 90 and above) to 20th century (Step 89 and below)timber treads and risers ©Robin Foster (Provided by Historic Royal Palaces)

Plate 56: Step 93 down to 82 showing transition from Victorian (Step 90 and above) to 20th century (Step 89 and below) timber treads and risers ©Robin Foster (Provided by Historic Royal Palaces)

Plate 57: Phase 1 (2016) removal of the timber cover over Step 92 ©HRP (Provided by Historic Royal Palaces)

Plate 58: The stairs following removal of the timber covers and cleaning (Step 64 to 75)

Plate 59: Damage to the Steps (Step 10)

Plate 60: Method of measuring each Step individually taking into account protective zotefoam strips Steps 26 to 28

Plate 61: Interlocking steel trays used to hold the new wooden covers in place (Steps 73-77)

Plate 62: Method of packing and protection used in anchoring the steel trays onto the historic staircase (Step 77)

Plate 63: The new covers can be removed individually to allow access to the medieval stone steps underneath (Steps 66 to 68)

Plate 64: Petrological assessment undertaken on uncovered and cleaned stairs (Step 38) ©HRP (Provided by Historic Royal Palaces)

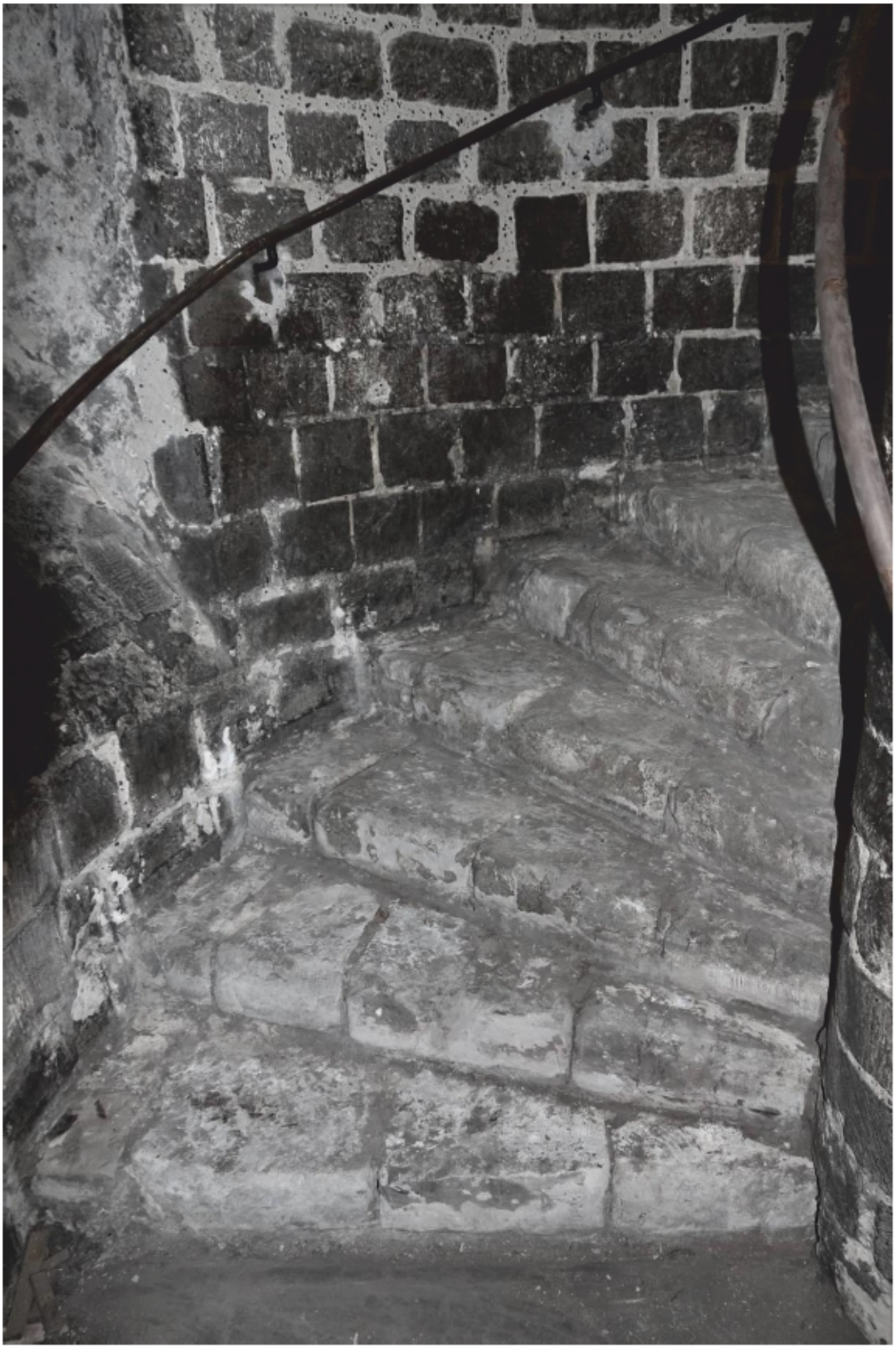


Plate 65: The lowermost medieval steps (Steps 1 to 6)

Plate 66: Dense shelly fawn mortar (T1) found in Steps 1 to 66

Plate 67: Chalk rich cemented mortar (T2) found in Steps 67 to 90

Plate 68: light-cream grey muddy micaceous limestone

Plate 69: Steps 8 to 11 showing damage caused by pegging into poor quality malmstone

Plate 70: Step 22 with fossiliferous limestone consisting of numerous horseshoe shaped thick shelled bivalve

Plate 71: Steps 33 to 35 showing the localised use of white chalk

Plate 72: Narrow diagonal axe markings on Step 1

Plate 73: Soft fawn very shelly cockle mortar (Type 1)

Plate 74: Soft fawn very shelly cockle mortar (Type 1) used as a bonding mortar in Step 9

Plate 75: Soft fawn very shelly cockle mortar (Type 1) used as a sealant or levelling layer beneath Step 9

Plate 76: Carbonised wood impressions found on Step 18

Plate 77: Soft fawn very shelly mortar (T1) filling the gap behind the small, irregularly shaped malmstone pavers in Step 51

Plate 78: Poorer quality malmstone in Step 56

Plate 79: The building break in the wall of the Flamsteed Turret continuing above step 61

Plate 80: The building break in the stair wall is shown by a change from ashlar to rubble above step 61

Plate 81: The building break in the wall of the Flamsteed Turret is shown by a change from ashlar to rubble above step 67, see arrow

Plate 82: Bembridge Limestone characterised by coiled snails of the fossil *Galba*

Plate 83: Bembridge Limestone characterised by coiled snails of the fossil *Galba*

Plate 84: Tool marks in Bembridge Limestone found on Step 74

Plate 85: Quarr stone in smaller, irregular and poorly worked blocks in Steps 89 and 90

Plate 86: Steps G1-G6 showing concrete and wooden additions made to the medieval stone in order to create the staircase

Plate 87: Steps B10 to B16: 1729 to 1753 hand-sawn stone steps

Plate 88: supporting courses of bricks beneath B1 to B4

Plate 89: Steps B5 to B7: 1729 to 1753 hand-sawn shelly Purbeck limestone pavers

Plate 90: Nosing of Step B5: 1729 to 1753 hand-sawn shelly Purbeck limestone pavers

Plate 91: Tread of Step B13: 1729 to 1753 Hopton Wood stone or marble used for its ability to be polished

Plate 92: Purbeck marble block in Step B14

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