

Fig. 1: contour map, showing location of Westminster Palace in relation to Thorney Island (adapted from The Final Sketch Plan (2006))

Stopping the rot: subsidence and structural damage at Westminster Hall

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Introduction

Westminster Hall is a Grade I Listed building with UNESCO World Heritage site status.² Much of the fabric of the building has been subjected to major sympathetic and unsympathetic

refurbishment. The last campaign, undertaken by Sir Frank Baines between 1914 and 1923, included the restoration of the famous oak hammer-beam roof.³ However, the construction and the history of the floor are relatively

unknown. In the recent past, several areas of the York Stone flag floor have been susceptible to subsidence. This problem may have, in the future, serious structural implications, in particular for the area between the Hall

and St Stephen's Chapel, including the South and West Steps. A multi-disciplinary team of specialists was commissioned by the Parliamentary Works Services Directorate to investigate the causes of settlement to the steps and floor in Westminster Hall, and to recommend proposals for works to arrest this settlement and repair the damage that had occurred.

In 2005, non-destructive surveys and geotechnical investigations were undertaken to identify the causes of settlement and to propose remedial action.⁴ All work was subject to archaeological observation and recording, and revealed significant defects that may be considered to be part of the ongoing problem. During these investigations archaeologists were given a rare opportunity to uncover and record significant archaeological deposits, features, structures and artefacts that gave clues as to how the Hall and the floor had been refurbished over the past 1000 years.

This paper will discuss the geotechnical properties and underlying stratigraphy of the floor, and explore the archaeological implications and options for consolidation of the floor and underlying deposits. I will also assess the impact of the conservation programme and how it affects the ethics of preservation *in situ*. I consider this aspect of the project important as it reveals some of the ethics and measures used by previous restoration programmes.

Palaeoenvironmental and prehistoric sequences

Westminster Hall and the adjoining Palace of Westminster both stand on Thorney Island (Fig. 1). The upper stratigraphy of the basal geology comprises alluvial deposition formed by river terracing. Underlying these deposits is the London Clay Formation.⁵ Seasonal groundwater was encountered at around 5 m below the present ground level of the floor.⁶

According to Thomas, the sediment sequence is complex, spanning at least 6–7,000 years.⁷ The sequence, comprising mainly well-sorted alluvium, clays, muds and sands, was revealed during the geotechnical investigations in 2005; this understanding was integral to the

project and design strategy to reverse the subsidence of the floor. Associated with this deposition are periodic changes to water levels, including those of the Rivers Thames and Tyburn. The changes in water level appear to have affected sediment deposition, especially during recent times when human activity on the island and the surrounding area has occurred. The earlier lithographic sequence appears to have been less complex, comprising a series of laminated organic muds that overlay sorted river and terrace gravels. The muds are the result of channel margin deposition and palaeo-channel dune systems, referred to as the Maidenhead formation.⁸ It extends along other sections of the Thames. The initial deposition of sediments occurred around 4,350 cal. BP and led to the formation of significant riverine dune systems known as the Thorney sand bed,⁹ the result of gentle and sporadic ebb and flow of the Thames.¹⁰ It is these sediments that form the deposition sequence beneath the floor of Westminster Hall.

The freshwater marsh appears to have stopped forming by the Middle Iron Age, at around 2,700 cal. BP, when it became subjected to more brackish estuarine conditions.¹¹ The tidal ebb and flow of the Thames appears to have stabilized the sedimentation regime, resulting in little erosion to the western shores of the island. However, significant erosion has taken place at the mouth of the Tyburn tributary.

Possible evidence for pre-Saxon activity was encountered in the MOSTAP¹² sampling and Cone Penetration Testing (CPT) programme (i.e. approximately 0.90 m below the existing floor level). The MOSTAP survey sampled the underlying deposits while the CPT survey measured their resistance, friction and strength properties, and determined whether or not sand or clay had been encountered at depths determined by ground penetration.¹³ The MOSTAP and CPT results contradicted a detailed account by Sydney Smirke in February 1836, which suggests that much of the stratigraphy within the first 1.5 m had been removed during his restoration programme.¹⁴ Deposition was roughly consistent across the footprint of the

building, and comprised a sequence of clean well-sorted sand and clay deposits, probably the result of low-velocity riverine alluvial accumulation along the western side of Thorney Island. These deposits contained no evidence of anthropogenic activity.

Little or no evidence of pre-Hall activity was anticipated. However, the geotechnical survey in 2005 revealed some un-dateable evidence of pre-Hall activity in the form of a crushed and compacted chalk floor level at around 0.96 m below the existing ground level (see below). Despite the shortcomings of the keyhole techniques used, it was considered that a significant archaeological resource exists.

Immediately north of the present building stock is the culverted River Tyburn. The most recent archaeological investigations, the archaeological excavation for the Jubilee Line Extension (JLE) undertaken between 1992 and 1998 during construction of Westminster Underground Station,¹⁵ revealed that the land east and north-east of the Palace of Westminster (including Westminster Hall) had an archaeological sequence that included early Holocene deposits (c. 8,500 – 4,000 BC).

Historical and restoration sequences

Westminster Hall was built between 1097 and 1099 for William Rufus and remodelled for Richard II in 1394–99; it has been described as 'the finest secular medieval interior in the British Isles'. The roof, the prime example of its type, is an outstanding engineering achievement, and is regarded as one of the superlative surviving pieces of medieval carpentry in the world.

Good documentary evidence and the recent archaeological investigations suggest that the floor levels have altered much over the past 200 years. However, it is the famous medieval hammer-beam roof that has received most attention, usually as a result of mitigation following fire damage, reconstruction and/or restoration. The first major restoration occurred in 1749–50 when the roof lead and slating was replaced. The removal of the lead revealed extensive decay and as a result the repair cost doubled.¹⁶

Until the latter part of the 18th century, the Great Hall hosted a

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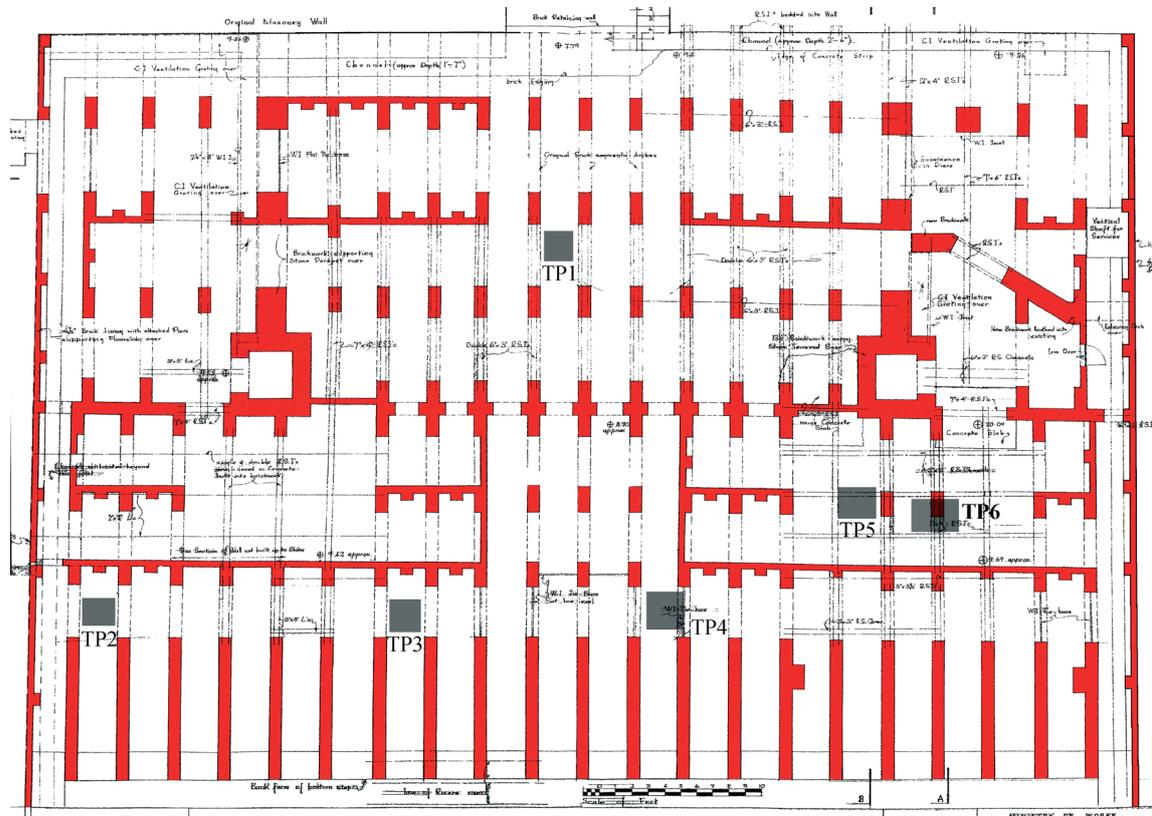


Fig. 2: plan of South Steps showing locations of Test Pits (from Barry c. 1850)

multitude of activities, including shopping. However, by 1780 the shops, which extended either side of the Hall, were removed, showing the walls and paving to be in a poor state of repair.¹⁷ The walls were refaced by 1782 and the floor level was raised by approximately 0.30 m.¹⁸

Major restoration programmes continued throughout the 19th and early 20th centuries, including Soane's 1819–22 reconstruction of the northern and western sections of the Hall. Soane was instructed to adhere to the architectural style of work undertaken during the reign of Richard II. By the mid-1830s large cracks started to appear in the walls of the Hall, probably the result of using poor bonding materials along with probable settlement and subsidence. It was during this restoration programme that the Palace of Westminster suffered a major fire on October 16th 1834. However, the Hall and its famous hammer beam roof survived unscathed.

Large squared York Stone flags, surviving as the present floor, supported by brick coursing and arches, were laid in 1836. The brick coursing, some sections later reused in the floor refurbishment in 1836, probably stood on the original medieval floor surface of crushed chalk. Between the flagstones and the original surface was a narrow cavity. This technique, according to the architect of the day, reduced the risk of rising damp and flooding. The floor was later lowered during Smirke's restoration programme of 1834–7 by around 0.42 m, to reveal a Purbeck Stone floor, believed to date to the reign of Richard II. Smirke's restoration programme re-laid the floor with the present York Stone flags.¹⁹ Despite the installation of the heating system during the late 19th century, the present floor, its level and the materials used, has altered little since this date.²⁰

The architect Sir Charles Barry, whilst constructing the new Westminster Palace in 1850, made

several alterations to Westminster Hall, including an arch which replaced the great south window, a large flight of steps which now lead from the Hall to St Stephen's Porch (Fig. 2) and strengthening and restoration of the roof. Gerhold suggests that the steps changed the ambience of the Hall from a room to effectively a corridor.²¹ Arguably, however, the steps do offer a certain elegance and have been used in the past by the monarch during formal occasions. Underneath the upper section of the steps leading to St Stephen's Porch is a brick-vaulted space that houses the central heating system. This area was later excavated in the Phase II programme and revealed significant structural remains of floors associated with the 18th-century floor, and Soane's door leading to the Law Courts. Other alterations, proposed by Barry but never executed, included large murals that would have hung on the walls of the Hall, and the construction of a wing that would have

replaced Soane's Law Courts. Barry's plan would have radically altered the northern elevation, raising the roof of the Hall by approximately 3.2 m.

Further restoration in 1883 under the direction of J.L. Pearson included the demolition of Soane's Law Courts. This exposed five flying buttresses along the western elevation, as well as revealing parts of an 11th-century building section along with masons' marks.²² Pearson appears to have applied an unsympathetic approach, replacing medieval stonework with something that he considered *architecturally correct*.²³

In the last major restoration programme, between 1914 and 1923, Sir Frank Baines undertook more sympathetic measures. He initially surveyed the Hall in 1912 and discovered that some of the timbers of the medieval hammer-beam roof were in a state of near disintegration.²⁴ An inspection in 1913 showed that the roof timbers were infested with death-watch beetle. According to his report, four of the thirteen trusses were in a state of near collapse; principal rafters had been eaten away along with two collar beams. These timbers weakened the hammer-beams that in turn supported the tracery. It also transpired that the iron ties installed by Barry had further weakened certain sections of the roof. As Gerhold poignantly remarks, if Barry or Pearson had discovered the extent of the decay, the 14th-century roof would have been completely replaced.²⁵

Baines's philosophy was to preserve as much timber as possible. He proposed that a steel supporting structure should be installed in order to relieve the load-bearing stress from the timbers. As a result, Baines managed to minimize replacement to just 10% of the timbers.

Since Baines' restoration programme, no further major works have been undertaken, although the roof did suffer some damage from incendiaries during World War II and from an IRA bomb in 1974.

Scope of the project

It became apparent by 2004 that various areas of the floor of Westminster Hall were prone to excessive settlement. More noticeable was the lower section of the South Steps, leading to St Stephen's Porch. Since the last complete restoration by Sir Robert Smirke in 1834–6, the floor had subsided up to 200 mm around the base of these steps. Other defects included settlement around the support pier for the Candelabra located south-west of the South Steps, severe cracking in the West Steps and a noticeable hollowing within the southern part of the floor area. Monitoring undertaken between 1992 and 2004 revealed that the subsidence had accelerated to 8–10 mm between these dates, whilst the steps had moved 16 mm within the same period.²⁶ It was suggested by the lead consultants – Gifford – that the problem was caused by the ground conditions beneath the floor. The

settlement of the floor and the subsequent damage is possibly the result of variation in the strengths of the upper soil stratigraphy, including alluvium, mud and sand.²⁷

Before the engineering programme and the remediation of the floor and steps, the area was excavated to a required depth based on the Phase 1 MOSTAP and CPT results as well as subsequent archaeological assessment.²⁸ First, ten York Stone flags (numbered 1–10) were lifted from within the floor area and six test pits were excavated underneath the South Steps (Fig. 2). Each of the cavities underlying the ten flags and the six test pits were recorded using conventional archaeological recording methods. These results gave some indication of the stratified deposits that lay beneath. However, it should be noted that during Smirke's restoration programme a sizable deposit that extended across the entire floor area was removed, groundworks were consolidated and the void reinstated with imported soils. The depth of the Smirke excavation and the deposits were recorded in correspondence between his brother Sydney Smirke and Sir Henry Ellis in February 1836 and his account contrasts with some of the interpretation from the borehole survey undertaken in 2005 (see Appendix 1).

Next, an archaeological excavation was undertaken. The base section of the South Steps was removed and underlying deposits archaeologically excavated. This section of the floor was remediated using a mini-pile system. The floor at the southern end was stabilised using dry rather than moist soils in order to prevent any further settlement. Finally, the cracks in the West Steps were re-pointed.

Archaeological and geotechnical considerations

The previous floor, constructed between 1834 and 1837, comprised a concrete bed on which a series of brick-coursed sleeper walls were laid (Fig. 3), to support a surface of York Stone flags. In some areas brick sleeper walls had been replaced by concrete sleeper beams. This repair may date to the early 20th century and the restoration work of Sir Frank Baines. The concrete floor, measuring between 350 and 400 mm



Fig. 3: brick sleeper walls on concrete bed of previous floor

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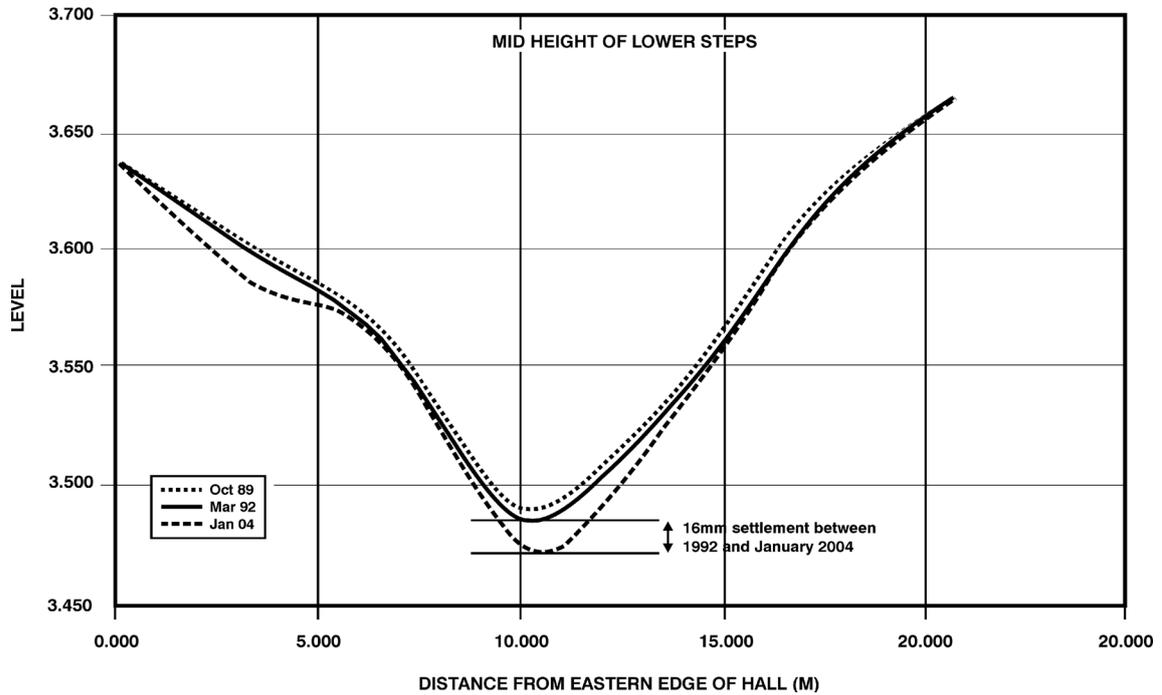


Fig. 4: graph showing settlement of the South Steps (adapted from The Final Sketch Plan (2006))

thick, overlay a brick and rubble foundation. The brick sleeper walls that supported the York Stone flags were constructed of brick types that were mainly reused and dating from the 16th/17th centuries. It is clear that these bricks were salvaged from dismantled building stock that either lay within or just outside the Hall, possibly the remains of coffee shops that stood within the Hall during the 18th century.

Most of the sleeper walls inspected showed little or no indication of settlement. However, an area immediately north of the South Steps showed severe cracks within the concrete floor on which the sleeper walls stood. Between 1992 and 2004 up to 16 mm settlement had been recorded within the area of the lower steps (Fig. 4). This settlement had acutely accelerated, compared with settlement recorded between 1989 and 1992 when only c. 1 mm had been recorded; however, irrespective of the rates recorded, settlement appears to have been an ongoing problem over the past 180 years.

The South Steps were designed and installed by Sir Charles Barry in 1850 (Fig. 2). The stone (Hopton Wood limestone) was supported by a complex

arrangement of brick piers and walls (Fig. 5). This brickwork sits on the same concrete floor that extends across the rest of the Hall. Based on the test pit investigations and documentary records the concrete floor dates to the Smirke restoration (c. 1834). Inspections of the

steps and the piers on which they stood showed that severe settlement in the form of diagonal, horizontal and shear cracking had occurred, especially around the area that supported the West Candelabra. Inspection of the spaces underneath the steps revealed that an



Fig. 5: steel reinforcing joists on piers supporting the South Steps



Fig. 6: West Steps, showing severe cracking

attempt to rectify the settlement had been made in the early 1960s, when steel reinforced joists had been inserted into the upper section of the brick piers (Fig. 5). However, some of the brick pier sections no longer provided support for the steps.

Within the western part of the Hall and located close to the South Steps are the West Steps, which were constructed by Pearson during his restoration programme, between 1883 and 1888. Recent investigations and monitoring has revealed severe cracking (Fig. 6). This ornate structure is also founded on the concrete bed that was probably laid some 50 years previously. Based on limited archaeological investigations in 2005, the area on which the steps are sited was once covered by York Stone flags. These were removed and Pearson laid a shallow concrete base, forming a foundation raft over Smirke's earlier concrete floor.

Recycling and the Parliamentary purse

It is clear that the present refurbishment of Westminster Hall will not be the last. Indeed, based on modelling and engineering predictions, the present refurbishment should stabilize the floor for at least 60 years.²⁹ The results from intrusive investigations undertaken by the Gifford team show that building materials were at a premium and that

much brick and stone, some of it decorative and dressed, was reused in previous restoration programmes such as those directed by Smirke, Barry and Baines (see Fig. 7). Evidence for recycling, clearly seen with the materials used for the floor sleepers, suggest that nothing was left to waste. For example, underlying floor flags 6 and 8 were 17th/18th-century brick that had been used along with later unfrogged brick types. It is probable that this material originated from various demolished buildings within the Palace of Westminster precinct. It is clear that building materials were being stored on site and used accordingly. The prudence of successive parliamentary procurement departments appears to show awareness of the cost implications of purchase and transporting new building materials. Although the brick sleepers date to



Fig. 7: dressed medieval masonry cut from a floor section, underlying the current floor level, probably used as foundation material.

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the Smirke restoration programme, other reused and salvaged material found elsewhere within the vicinity of the Hall does not.

In the Phase 1 programme six small test pits, each approximately 0.50 m square, were excavated underneath the South Steps (see Fig. 2), where the greatest settlement of the floor had taken place. They all revealed a similar stratigraphy to that of the floor area, between 350 mm and 450 mm of concrete overlying a small but significant rubble deposit. The base of each test pit extended to this deposit and no deeper. However, within Test Pit No. 5, and partially supporting one of Barry's brick piers, was a large dressed piece of masonry, thought initially by the author to be a medieval widow tracery section, measuring 0.60 m by 0.40 m and constructed of Purbeck limestone. Closer inspection and verification from the Palace of Westminster's archivist Dr Mark Collins and Conservation Architect Adam Watrobski revealed that it was in fact a trestle section that once belonged to the King's Table, constructed during the 13th century, probably during the reign of Henry III or Edward I. This piece of furniture stood in the Hall until the Commonwealth years of the mid- to late-17th century (Figs. 8, 9). The trestle section (one of probably eight sections) is considered by archaeologists as a significant artefact. Indeed, one of the eight sections, discovered some years previously, is on display in the nearby Jewel Tower (Fig. 9). It is more than probable that yet again financial prudence was the order of the day, and that the trestle section was used as foundation material during Barry's construction of the South Steps around 1844.

Concluding remarks: ethical approaches to archaeology and building conservation

Since the introduction of PPG15 and PPG16 in the early 1990s, there has been, in my experience, little synergy between archaeology and building conservation. However, at Westminster Hall there was a clear relationship between these two Guidance Notes and the geotechnical investigations and later engineering remedial work. This project in terms of archaeology also extended



Fig. 8: trestle section of the King's Table, as found

beyond the usual 'excavate and record' procedures. It was important to establish a narrative, in particular to understand the ethics of previous restorations which, in my view, provide an important archaeological resource. It is probable that the stratigraphy recorded directly underneath the concrete floor on which the sleeper walls and York Stone flags sit requires further careful reassessment, especially if one is to take seriously into consideration the contents of Sydney Smirke's letter of 1836 (Appendix 1).

The ethical approaches taken in order to mitigate the archaeology before and after the engineering remediation of the floor deserve comment. Based on the preferred engineering option, it is clear that there was going to be an impact on the deposits that lie beneath the concrete floor. It was also considered by the design team that the archaeological component would provide some, but not all, the answers to the construction methodology and materials used for previous floor refurbishments (Fig. 7). The materials and construction methods used gave some indication of the ethics of the Hall's early builders and users. From the evidence collated from the Phase 1 programme it appeared that careful choice and use of materials had been considered as of paramount importance. The history of the Hall

floor, especially over the past 180 years is significant in that large areas of the potential underlying archaeology was either destroyed or disturbed (Appendix 1). However, the combination of the geotechnical investigation and engineering programme, the archaeological recording and the extensive documentary archive has allowed greater detail to be added to an already complex history. Furthermore, a staged and ethical approach has been instigated and the true spirit of *preservation in situ* has been allowed to work along side more pressing matters.

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Appendix I

Correspondence between Sydney Smirke and Sir Henry Ellis, dated 4th February 1836:

"In forming the new pavement, it has been necessary to remove the ground every-where to the depth of at least four to five feet [>1 m] below the level of



ig. 9: trestle section of the King's Table, after cleaning

the Yorkshire flagstone floor laid at the latter end of the last century; about one foot four inches below that level, another floor of Purbeck stone was found, the level of which appears, from the door jambs finishing down on to it, to have been that adopted in Richard the Second's time [reigned 1377–1399]; this level has therefore been fixed on for

the new pavement, and the additional height thereby given to the walls of the Hall much improves its architectural effect, at the same time that the original proportions of the building are restored.

The whole of the area has now been explored, in some places to a considerable depth, but no certain indications have any where been

discovered of any still lower floor.

Immediately beneath the Purbeck floor was a thin stratum of variable thickness, averaging seven or eight inches, and consisting chiefly of a compressed black soil: this lay upon a bed of well-tempered and pure clay four or five inches thick, extending uniformly over almost the area of the Hall, but seeming in some places to have been worn as it were into hollows; this may possibly have been the surface of the floor in the earliest state of the Hall, and the thin stratum of black earth found upon it, may have been the accumulation necessarily arising from the long continued use of the earthen floor.

Beneath the above-mentioned layer of clay, which was found to be a few inches thick, was a bed nearly three feet thick of made earth, consisting of stone rubbish, lime core, clay and sand: and finally, under all, and extending uninterruptedly over the whole surface of the Hall, was found a compact bed of clay, evidently artificial, which varied in depth from about four to five feet. But which uniformly was found to lay upon the natural and undisturbed soil, consisting of gravel and sand, containing every where much water.

Although, in the formation of the new pavement, it became necessary to remove the ground every where to the depth of about five feet, and in some places much deeper."

1. Department of Archaeology and Anthropology, University of Bristol, and formerly of Gifford Ltd.
2. *Westminster World Heritage Site Management Plan: Consultation Draft*. Atkins (2004).
3. L.T. Courtney 'The Westminster Hall roof and its 14th Century Sources' *J Soc Architectural Historians* 43 (1984) 295–309.
4. The data collection process and mitigation strategy were outlined in a document entitled *Westminster Hall: Steps and floor Final Sketch Plan Proposal* (2006).
5. C. Thomas, R. Cowie and E.J. Sidell *The Royal Palace, and Town of Westminster on Thorney Island. Archaeological excavations (1991-1998) for the London Underground Limited Jubilee Line Extension Project* (2004).
6. Seasonal variation was around 2 m, between 4 and 6 m.
7. C. Thomas 'The Archaeology of Thorney Island' in J. Sidell, K. Wilkinson, R. Scaife and N. Cameron (eds), *The Holocene evolution of the London Thames: archaeological excavations (1991-1998) for the London Underground Limited Jubilee Line Extension Project*. MoLAS (2000) 21–24.
8. D. Gerhold *Westminster Hall: Nine Hundred*

Years of History (1999) London.

9. J. Sidell, et al, *op. cit* fn 7.
10. Nash has also recognised similar sediment deposition at Hopton Street, Southwark where Pre-Construct Archaeology undertook an evaluation in 1994, see G.H. Nash *An Assessment of the lithic assemblage from the Hopton Street evaluation programme, Southwark*. PCA Report No. 003 (1994). At the base of the trenching was found a small lithic assemblage that included diagnostic Neolithic flint, later revised by B. Bishop *Excavations at Hopton Street, London Borough of Southwark. Lithic Assessment*. PCA (1997), unpublished report. Overlying the flint and located some 4.30 m below the existing ground level were a series of well-sorted riverine sediments and regoliths.
11. *Op cit* fn 9.
12. *Monster Steek Apparaat* (Sample push apparatus).
13. The CPT survey would also determine the load-bearing qualities of the soils.
14. S. Smirke 'Second letter from Sydney Smirke, Esq. FSA, to Sir Henry Ellis, FSA, Secretary, on the architectural history of Westminster Hall' *Archaeologia* 26 (1836) 415–

420. (416). See Appendix I.

15. Museum of London. *New Palace Yard, Westminster Palace. Excavations in advance of the Jubilee Line Extension* (1994); *op cit* fns 5, 7, 9.
16. F. Baines *Report on the Condition of the Roof Timbers of Westminster Hall*. Cmd. 7436 (1914); I.M. Cooper 'Westminster Hall' *J British Archaeol Soc* 00 (1937) 3–63.
17. *Op cit* fn 8, 62.
18. *Ibid*.
19. S. Smirke 'A further account of the original architecture of Westminster Hall' *Archaeologia* 27 (1837) 135–9.
20. *Op cit* fn 8, 62.
21. *Op cit* fn 8, 65.
22. *Ibid*; Cooper *op cit* fn 16.
23. *Op cit* fn 8, 66.
24. *Ibid*; Baines *op cit* fn 16.
25. *Op cit* fn 8, 68.
26. Gifford. *Westminster Hall: Steps and Floor, Final Sketch Plan Design Proposal* (2006) 10.
27. *Ibid*, 21.
28. *Ibid*.
29. *Ibid*, 35.