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'Another wall of turf': geoarchaeological analysis of the Antonine Wall at 72 Grahamsdyke Street, Laurieston, Falkirk

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ABSTRACT

Excavation of a well-preserved stretch of the rampart of the Antonine Wall east of Watling Lodge, at Laurieston, allowed for the first micromorphological study of its earthen building materials. This revealed that the rampart core, as well as the cheeks, were constructed in well-layered courses of turf blocks – but sourced from different grasslands. The evidence differs from macroscopic observations made at other sections in this area where the rampart material had been interpreted as representing a loose earth core with clay cheeks. Our results show that even when the characteristic striped sections indicative of turf are not visible in the field, thin-section analysis can confirm the use of intact soil blocks with the remains of grassed surfaces. It now seems possible that the visible variation between materials in the eastern and western sectors of the Antonine Wall may simply be due to different types of turf used, varying in subsoil composition and topsoil formation, and representing differences in landscape management and survival of vegetation. Combined with macroscopic field recording to identify Roman building practices, our analysis of this section at Laurieston also shows the care that was taken to construct a level, well-draining base for the rampart to avoid slumping and moisture build-up. Further excavations and thin-section analysis elsewhere along the Wall are now needed to confirm whether turf was more extensively used than so far anticipated for the eastern sector and whether the Antonine Wall could possibly have been built completely of turf. Such conclusions would suggest a much more standardised construction process and more extensive grassland exploitation than considered up until now. While our results demonstrate the importance of micromorphological analysis for understanding this earthen UNESCO World Heritage site, our interdisciplinary approach may also have wider relevance for research on linear earthworks in different geographical and chronological settings.

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INTRODUCTION: THE *CAESPES* OF ANTONINUS PIUS' *MURUS CAESPITICIUS*

The only surviving written account to mention the construction of the Antonine Wall tells us that it was made of turf, *caespes* in Latin. This is the passage of the *Historia Augusta* which explains that Antoninus Pius 'defeated the Britons through the legate Lollius Urbicus, building another wall of turf [*alio muro caespiticio*], after driving away the barbarians' (*Scriptores Historiae Augustae*, *Antoninus Pius* 5.4, translated by T Romankiewicz and F Guidetti; see Romankiewicz et al 2020a: 121, and translation by Hanson & Maxwell 1983: 75: 'a turf wall'). Archaeological interventions since the late 19th century, however, have suggested that the structure of the Antonine Wall was perhaps more heterogeneous than the *Historia Augusta* implies. While sections cut across the rampart in the Wall's western sector have tended to show continuous horizontal black or reddish lines corresponding to the original grass surface of well-layered turf blocks (eg GAS 1899: 73), excavations by Macdonald east of Watling Lodge, Falkirk, have indicated that this part of the rampart might have been built with an earth core, faced by turf or even clay cheeks (Macdonald 1915: 120–2; 1925: 281–5; 1934: 86–7; see comments by Hanson & Maxwell 1983: 80; Breeze 2006: 74; Hanson & Breeze 2020a: 12). Later work has, however, demonstrated that this eastern part was much more varied in terms of its construction (Keppie 1976: 71, 77–8). Despite this apparent variation, and the fact that the Antonine Wall is one of the largest and best-preserved earthen structures to survive from the Roman world, it has never been analysed using geoarchaeological methods (though see Romankiewicz et al 2020a for a first geoarchaeological perspective on the monument). In particular, the building materials of the Antonine Wall rampart have never been studied microscopically to analyse their characteristics, sourcing and use.

In this paper, we present the results of new micromorphological analysis of a series of samples taken from a section through the Antonine Wall at 72 Grahamsdyke Street, Laurieston, Falkirk, outside the scheduled area. The methodology applied builds on that already used in the analysis of Roman turf ramparts at Vindolanda (Russell et al 2021), with the micromorphological analysis undertaken by the geoarchaeological specialist on our team (Gardner 2020; 2021). Micromorphology, combined with careful macroscopic documentation during excavation, provided important insights into the preparation of the ground surface prior to the construction of the Antonine Wall at this site, the materials used to construct the different parts of the rampart, and how these were employed. These results have important implications for understanding the broader context and construction of this monument as well as of other Roman fortifications in earth and turf. More widely, our work could provide new impetus for studies of linear earthworks and turf monuments elsewhere and from different periods, especially within existing geoarchaeological frameworks (eg Holst & Breuning-Madsen 2013; Kupiec & Milek 2015).

THE MORPHOLOGY OF THE ANTONINE WALL EAST OF WATLING LODGE

Accurately identifying earth materials and building techniques macroscopically is not straightforward. The appearance of turf blocks ultimately depends on the characteristics of the grassland from which they were sourced and preservation conditions at the building site. Sections through turf structures vary hugely in appearance, both in comparison to each other as well as across their own surfaces. Turf blocks with a thick layer of preserved organic material look quite different during excavation to those where the grass layer has been disturbed or lost, either prior to use – due to erosion, overgrazing, or trampling, or because it was deliberately trimmed off – or as a result of post-depositional conditions. Turf blocks cut mostly from lower soil horizons can appear quite different from those comprising topsoil and vegetation layers (for various examples, see Russell et al forthcoming). This makes distinguishing macroscopically between structures built entirely in turf and those constructed in a combination of turf and dumped earth extremely difficult, especially where turf and loose earth were sourced from the same soils (Russell et al forthcoming; compare Romankiewicz et al 2020b).

These are important points to consider when determining the details of construction of the Antonine Wall, especially in its eastern sector. The Wall core make-up in this area has been described as mixed earth, sometimes with turf blocks thrown in, and often containing sand or sand lenses as well as occasional clay-rich material (eg Keppie 1976: 77–8). It is worth noting that at Polmont Park, Bantaskin and Callendar Park, for example, where the core of the rampart was identified in the field as earth/clay, the grass lines of turf blocks were still noted in places and assumed to have been lumps of turf dumped into the core as well as some blocks measuring at least 0.4 by 0.2m across (Steer 1961a: 94 (ii), compare (i); 1961b: 322; Keppie 1976: 71–2; Bailey 1995: 580; further discussion below).

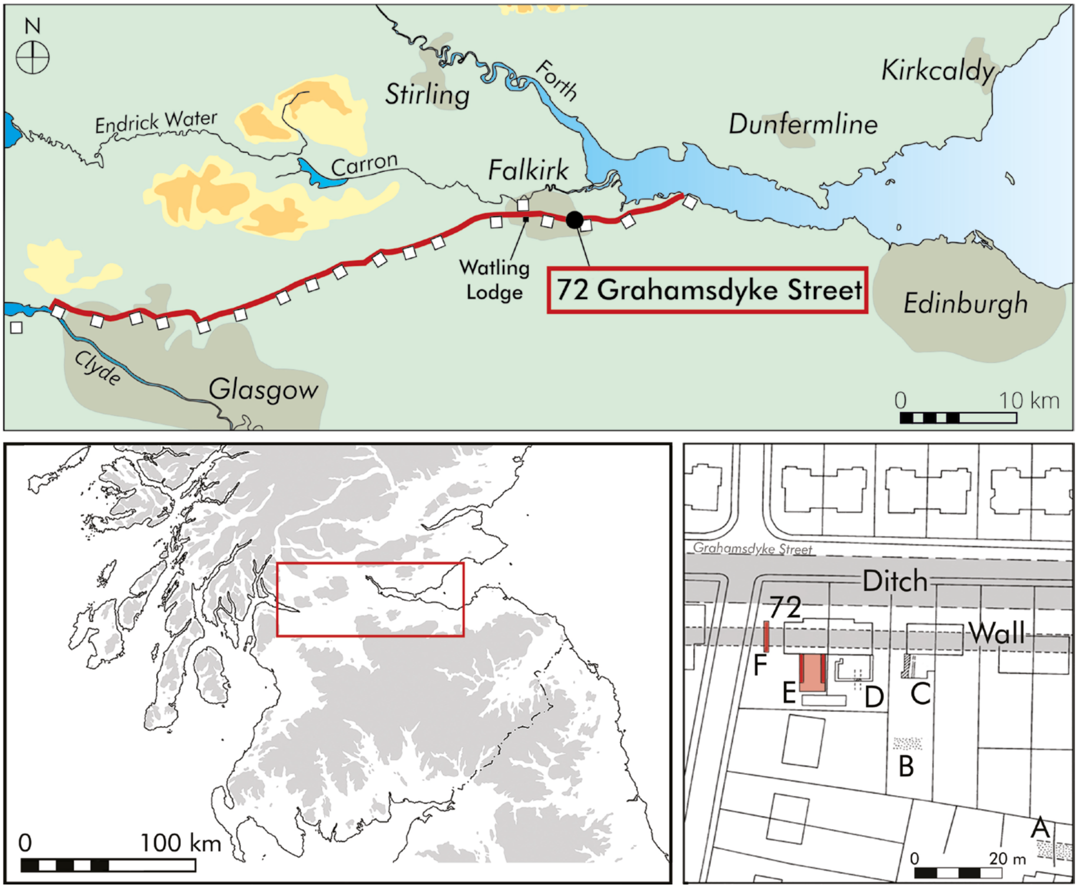
While Macdonald saw clay cheeks as the dominant facing material in this eastern sector of the Wall (Macdonald 1925: 283–5), many excavations since have recorded turf cheeks, to the extent that it has recently been suggested that clay cheeks were a later repair, especially in the area around Mumrills and its annex (Bailey 2021: 19, 312; compare Steer 1961a: 95). However, at Bantaskin for example, the original cheeks as well as a repair were built with turf, identified by ‘horizontal rusty-brown lines … [instead] of the dark (often dense black) lines’ (Keppie 1976: 71–2). As Keppie pointed out already more than 45 years ago, referring to observations by Robertson, ‘[i]t seems possible that the clay cheeks seen by Macdonald were in many cases likewise of turf cut on a clayey soil, turfwork in which the familiar horizontal black stripes were not visible’ (Keppie 1976: 77; compare earlier, shorter references in Keppie 1974: 161). The clay patches described by Macdonald in the core could then relate to similar turf blocks or offcuts from the clay-rich turf cheeks (Keppie 1976: 78).

Keppie’s observations raise a serious issue with our current understanding of the materials and construction techniques of the Antonine Wall: namely, that the conclusions drawn to date about the structure have been derived exclusively from macroscopic observations made during excavation. As Keppie points out, where certain stretches of the Wall’s superstructure lacked the regularly striped appearance of turf blocks, and where cheeks consisted of pale soil, it was often (and not unreasonably) assumed that these stretches were built simply of earth packed in place between clay cheeks. Our work at Laurieston set out to explore precisely these points, using a combination of macro- and microscale analyses.

EXCAVATION AND SAMPLING AT 72 GRAHAMSDYKE STREET

The new work on the Antonine Wall at Laurieston reported here was undertaken in connection with modern construction works at 72 Grahamsdyke Street (NS 9135 7953, Canmore ID 82858). A first, small-scale investigation in September 2019 revealed collapsed turf material to the rear of the rampart in two strip trenches and an area cleared of topsoil in between (Illus 1, trench E; Bailey 2021: 370–1; see Gardner 2020). Follow-up work in advance of the planned construction of a garage opened a section through the rampart itself in August 2020. This trench F averaged 1.1m wide by 8m long (7.8m west, 8.1m east), oriented north/south perpendicular to the Wall (Illus 1). Excavation was undertaken by the present authors and members of the Falkirk Local History Society and Edinburgh Archaeological Field Society. The current analysis forms part of the Earthen Empire project (Leverhulme Trust RPG-2018-223) at the University of Edinburgh, led by Ben Russell, and is based on micromorphology reports by Tom Gardner (2020; 2021).

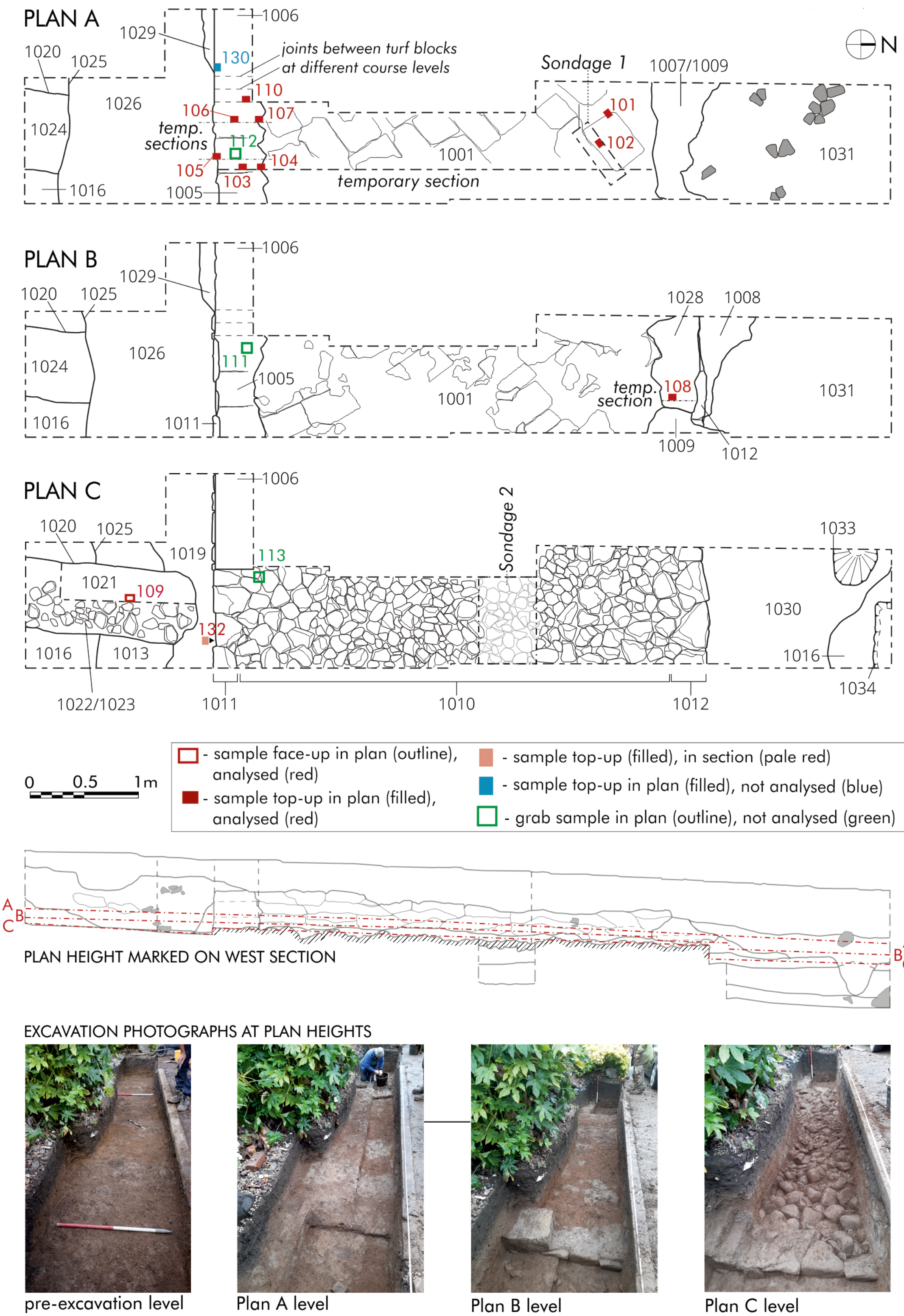
The excavations uncovered the full width of the Antonine Wall rampart, a section of the berm to the north, and the remains of a structure built against the back of the rampart to the south (Illus 2). The rampart superstructure, which was preserved to a height of 0.35–0.40m, was excavated and documented in plan at various excavation stages, and through section drawings and digital photogrammetry, with close attention to



Illus 1 Location plan. (© T Romankiewicz, G Bailey)

constructional details. As the stone base of the rampart lay below the level to be disturbed by the garage foundations, it was not removed and only tested by a small sondage through its centre to examine its condition and the soils below. In what follows we will focus on the data that could be extracted from the rampart and its base, with a brief word on the features identified to the north and south, especially where related to further turf construction.

A total of 33 samples were taken (and numbered S101–S133), of which 28 were processed (S101–S110, S114–S129, S131–S132; numbered in red for clarity without the 'S' prefix in the illustrations); 20 of these were from the rampart itself and the area immediately beneath it to test its materials and construction methods (Table 1, groups 1–4). In order to understand better the deposits on the berm and remains to the south, eight samples were taken from these areas (groups 5–7). Samples were prepared as thin sections for micromorphological analysis using a standard procedure (explained in Russell et al 2021: 183–4). This resulted in 30 slides, since Sample 116 was divided across three slides (S116A–116C). A total of 94 microstratigraphic units were identified and are fully discussed in the micromorphology report (Gardner 2021). These microstratigraphic units are labelled by the slide number followed by the letter of the unit within the thin section (eg slide S117, unit A = S117.A).



Illus 2 Trench at three different levels of excavation. Samples identified by three-digit numbers in red, contexts by four-digit numbers in black. (© B Russell, T Romankiewicz, J R Snyder)

Table 1
Micromorphology samples analysed by constructional element

Group no.	*Constructional element*	*No. of samples*	*Applicable sample (S) no.*
1	Turf blocks in Wall core	8	**101**, **102**, **119**, **120**, **122**, **123**, **126** (*with interleafing from south cheek*), **127** (*with interleafing from south cheek*)
2	Turf blocks in south cheek	7	**103**, **104** (*some core material*), **105**, **106**, **107**, **110**, **124** (*some core material*)
3	Turf blocks in north cheek	1	**108** (*some collapse*)
4	Levelling layers above/below stone base, including lower subsoil	4	**117**, **118** (*some core material*), **121** (*some core material*), **125** (*some core material*)
TOTAL rampart samples		**20**	
5	Material in front of rampart to north: collapse, deposits on berm	3	**114**, **115** (*contains in situ soil below collapse*), **116** (*some in situ north cheek blocks*)
6	Material behind rampart to south: collapse, deposits/infill behind and below rampart	3	**128**, **129**, **132**
7	Slot foundation in south for north/south structure against rampart	2	**109**, **131**
TOTAL other samples		**8**	

THE CONSTRUCTION OF THE ANTONINE WALL AT 72 GRAHAMSDYKE STREET

The combination of macroscopic observations and micromorphological analysis reveals a range of details about the construction of the Antonine Wall rampart at 72 Grahamsdyke Street. Both scales of evidence are therefore discussed together for the different stages of construction, which are arranged in their chronological sequence.

GROUND PREPARATION AND THE LAYING OF THE STONE BASE

Sampling immediately beneath the stone base, as well as on top of it, showed that considerable effort was put into providing a sound and level platform for the rampart superstructure, so ensuring its stability. First, the existing ground surface was stripped of its turf, terraced, and levelled. A bedding layer was then dumped across this stripped surface and the stone base was laid down onto this. Finally, a levelling layer was placed on top of the stone base to even out its irregularities.

In order to provide a level base for the rampart, the southern part of the naturally sloping ground was terraced into (by cut C1025) to level it with the northern part (Illus 3 & 4). The undisturbed soil C1016, sampled under the bedding layer of the stone base in the sondage and on the berm, comprised a relatively solid, weakly podzolised soil (B horizon) containing gravels and sands derived from glacial till (eg unit S117.B; Gardner 2021: 16, 27–9, 60–3, fig 17, table A1.13). It also contained some heavily weathered charcoal fragments, of the sort often interpreted as the signature of prehistoric farming practices, assumed to have constituted a slash-and-burn agriculture; this indicates when this lower soil was last cultivated. The podzol supported a likely acidic grassland, although the lack of topsoil (A horizon) or vegetation cover (O horizon) suggests that the latest prehistoric soils and vegetation had been removed as part of the levelling operations.

These horizons were probably cut as turf blocks and reused to build the superstructure, as discussed below, because the material of the rampart shows the same signs of eluviation indicative of weak podzols and acidic grasslands (C1001, eg S118.B–C, S120A–B for turf blocks from core, Gardner 2021: 8, 61, 65). In the field, C1016 underneath the stone base appeared similar, at least macroscopically, to the lower soils exposed on the berm (C1016) and what must be redeposited material dumped into the construction cut C1025 visible to the south (C1013; Illus 3 & 4 and further discussion below). Micromorphology confirmed that C1013, in units S129.C and S132.A, was indeed of similar character to C1016 in unit S117.B, but stratigraphically was comprised of soils redeposited within the construction cut (see below).

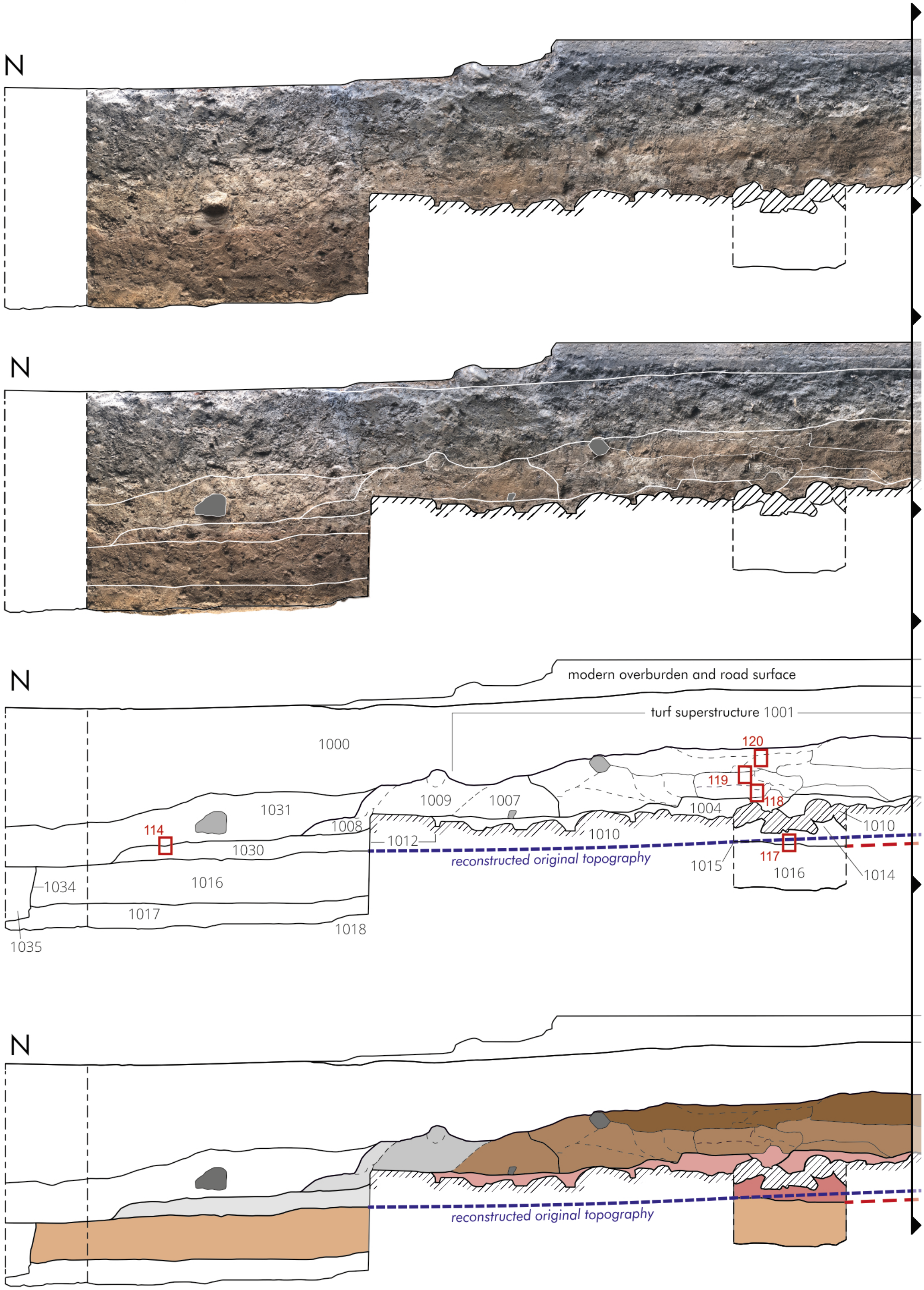
Sampling on the berm targeting the natural ground surface and any built-up erosion in front of the Wall suggested that S116C.D had just caught the top of the in situ soil C1016, which also had its vegetation stripped off for use as turf blocks. Seemingly, the turf had peeled off at a natural accumulation of iron panning that had formed below the topsoil when the vegetated ground surface was still intact. Such panning typically occurs at the interface between an A-horizon topsoil and a less permeable B-horizon subsoil. This pan was visible during excavation in the sondage as a general layer C1015 on top of C1016 but was much more fragmented at microscale (compare lack of this layer in S117.B and broken fragments in S116C.D, Illus 6a, b); this fragmentation seems likely to be a sign of disturbance of the iron pan caused by the turf cutting.

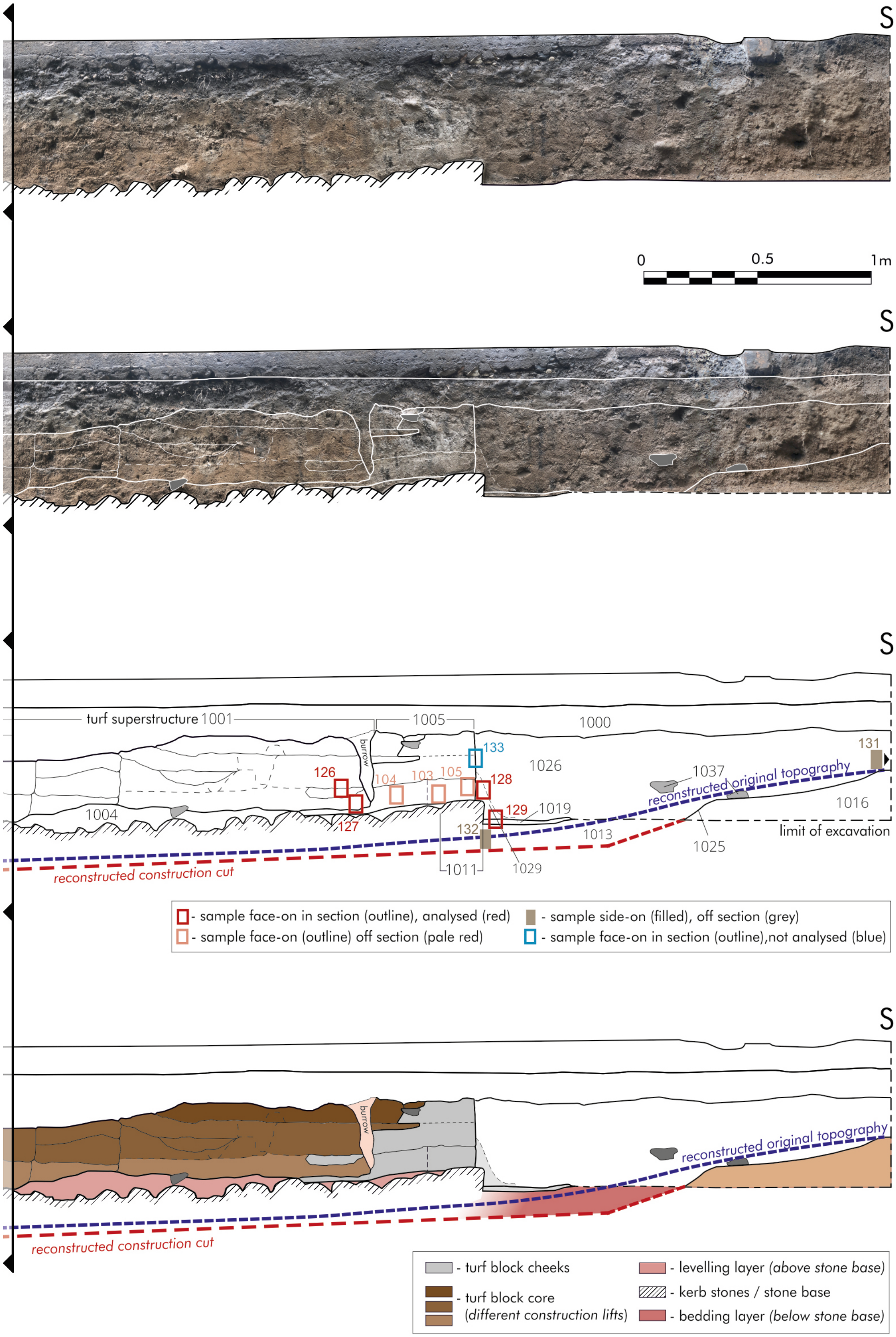
The surface of the C1016 soil on the berm was also notably compacted, indicative of heavy traffic likely associated with the construction processes for the Wall. This traffic would have rendered the soil surface less permeable to rainwater percolating downward and to the minerals carried down by it, which over time would have added to the existing crust of iron panning, as seen in C1015 under the stone base and in the fragments in S116C.D.

Compared to the other soils identified on site, unit S115.B, sampled further north on the berm, was of very different character; this was a well-aerated, buried brown earth usually associated with shrubs or woodlands (Gardner 2021: 16, 52, fig 16, table A1.9). As the overall context C1016 on the berm was unlike what was identified in the 75 × 50mm window of sample S115 (see Illus 4, small area shaded in blue), it seems that unit S115.B unintentionally sampled an area of an earlier tree throw or similar. This likely relates to early prehistoric activity, as the later prehistoric topsoil in this area had been removed during stripping of the site – and reminds us that micromorphology will only ever provide a narrow window within an overall much larger stratigraphic layer.

The stone base of the rampart was not laid directly onto this truncated and trampled palaeosol, likely because this surface had become too impermeable for drainage; if the structure had been built on this solidified surface, it would have been counterproductive for the drainage function of the stone base. Water could have collected on top of the trample and built up within the stone base, perhaps even soaking up into the superstructure. Instead an additional, sandy silt layer with some gravels (C1014, unit S117.A, Gardner 2021: 16, 60–3, fig 17, table A1.13) was added; this new layer was on average 0.15m thick and its likely source was the spoil from the levelling works. It acted as bedding for the stones of the base, which could be pressed into the loose material for added stability rather than just sitting on top of the hard, trampled ground C1016. This sediment also contained some cultural material including mortar and charcoal, probably the residue from other contemporary building activities. Articulated fragments of A- and B-horizon material within it seem to represent offcuts from sourcing turf blocks in this area. Certain features within the micromorphology of this bedding layer indicate that this material was deposited in a semi-saturated state, visible as voids in the form of polyconcave vughs and fine particles well sorted by granular size. Experimental work by the Earthen Empire project suggests that lightly wetting such gravelly silts aids the looser material to mould around the turf chunks and coarse fraction within it, as well as helping to embed the stones of the

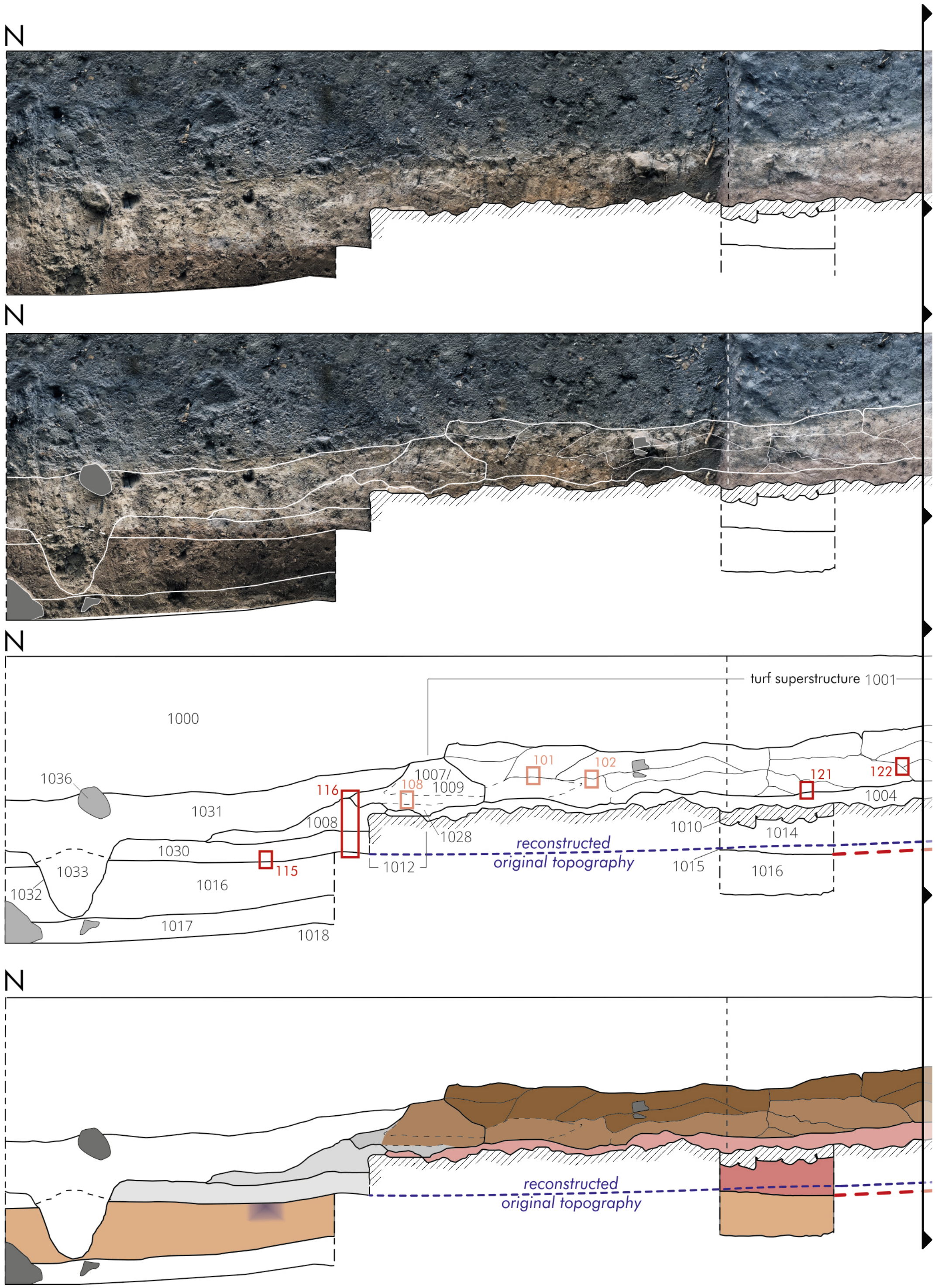
EAST SECTION

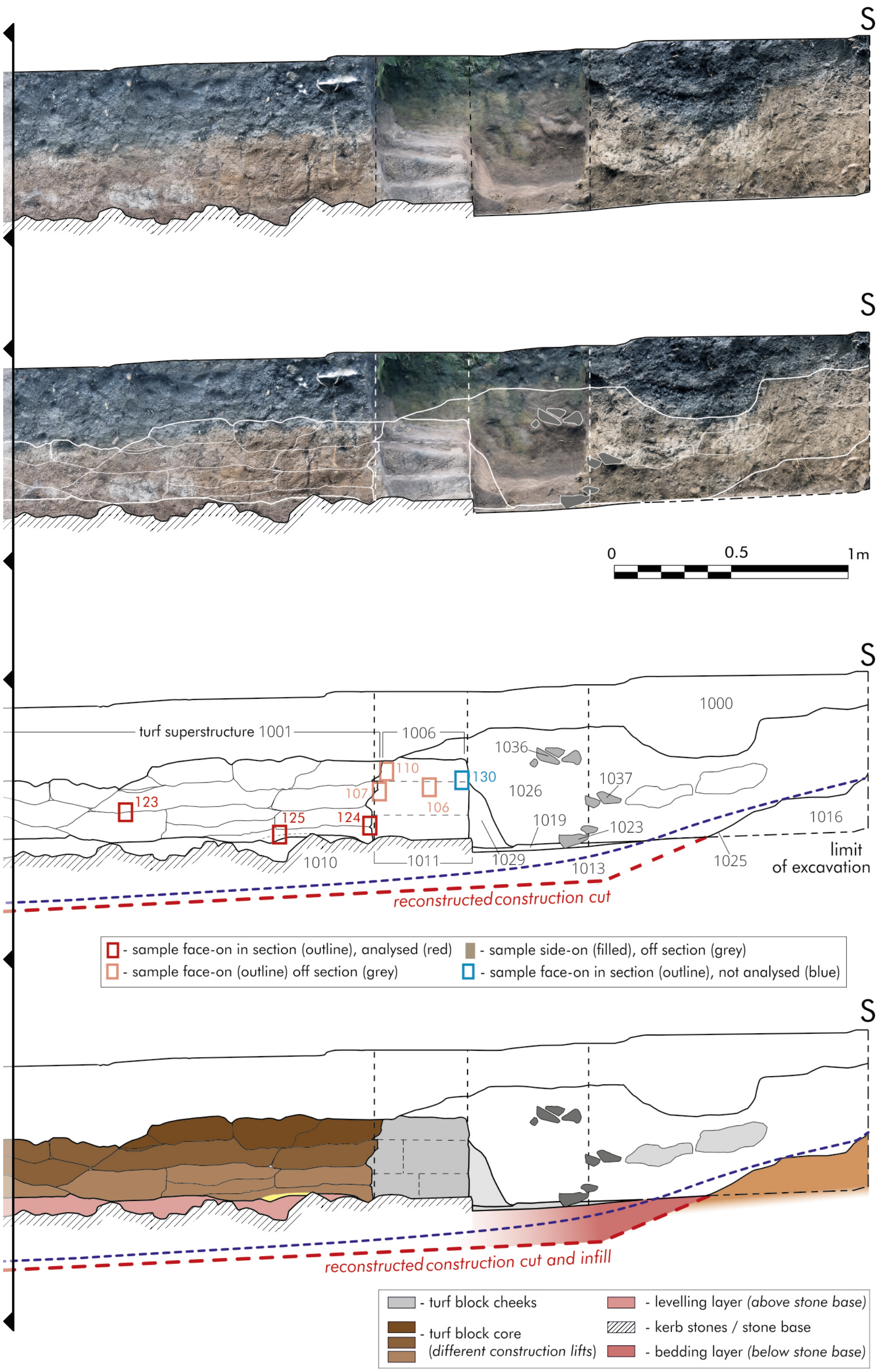




Illus 3 East section: photogrammetric recording and transcription, line drawing with sample location, and colour-coding of structural elements. Samples are identified by three-digit numbers in red, contexts by four-digit numbers in black. (© B Russell, T Romankiewicz, J R Snyder)

WEST SECTION (reversed)





ILLUS 4 West section: photogrammetric recording and transcription, line drawing with sample location, and colour-coding of structural elements. Samples are identified by three-digit numbers in red, contexts by four-digit numbers in black. (© B Russell, T Romankiewicz, J R Snyder)

stone base – but it is also possible this layer simply got rained on during construction.

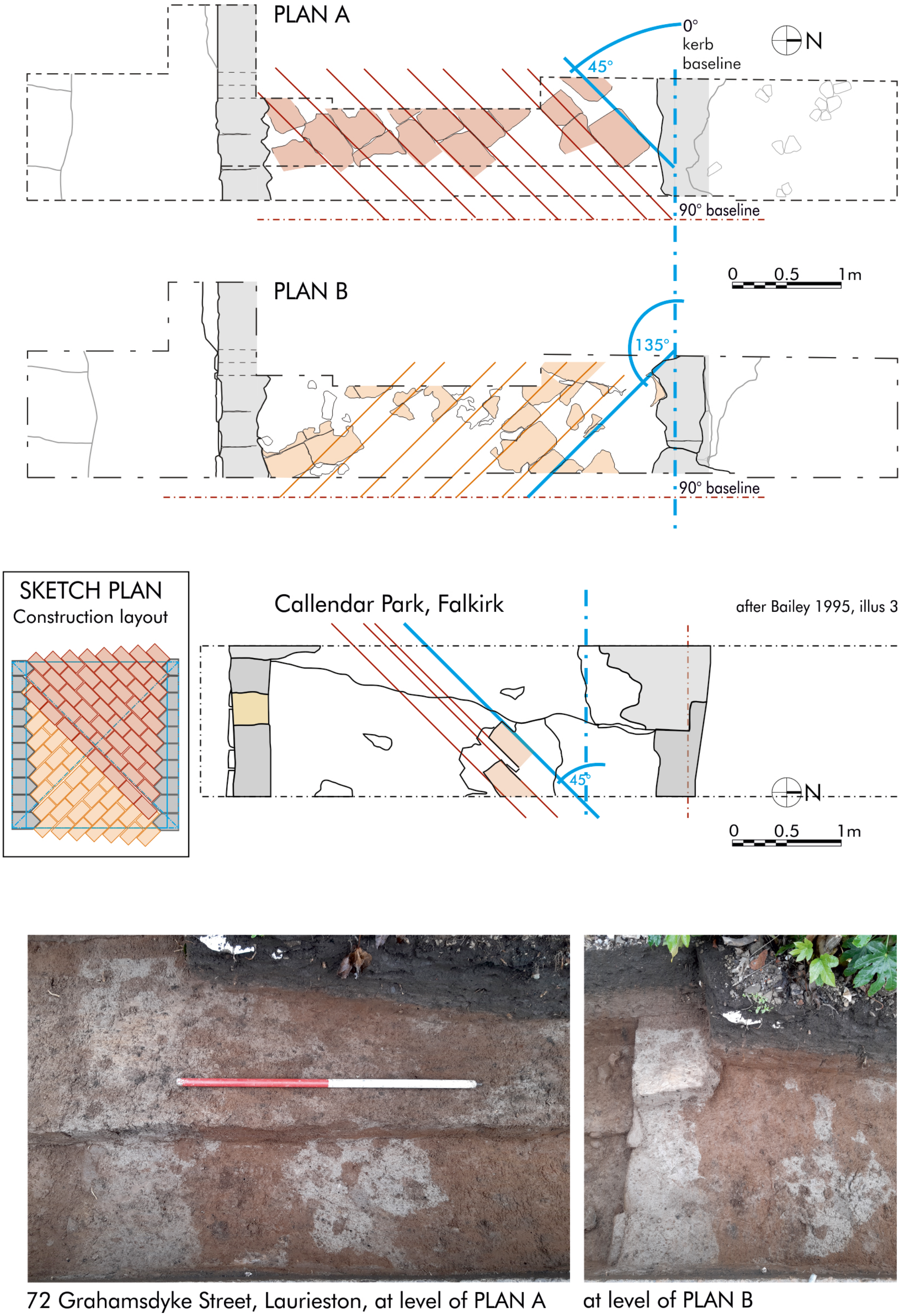
The stone base itself consisted of a raft of smaller stones C1010, spread between parallel southern and northern kerbs, C1011 and C1012. The raft comprised both well-rounded cobbles of various rock types and more angular pieces of sandstone of differing colour and density. It was noticeable that the angular pieces of sandstone were distributed towards the margins of the raft and that there was a cluster of smaller stones in the centre, particularly on the west side of the trench. This pattern is consistent with previous suggestions that cartloads of stones were brought in, each slightly different in content depending on the source, and then dumped into heaps and spread out (Bailey 2021: 10, 313). The more angular material, put immediately behind the kerbs, seems to have been carefully placed as kerb support (as seen elsewhere in the area, Bailey 2021: 10). The kerb stones were also all sandstone, but those in the north kerb were larger than those in the south and placed with their long axes parallel with that of the rampart. The southern kerb stones had their triangular tails set into the core of the base. Both sets of kerb stones had been crudely knapped to produce a cleft face that had been carefully placed in a vertical plain. This must have required small propping stones under the tail of the stones, but as the kerbs were not lifted in this excavation, this could not be confirmed; no chippings from the working of the kerb stones were found in the raft of the base, however. At 4.61m, the stone base at 72 Grahamsdyke Street was wider than average but lies within the upper limits of the known variation (Keppie 1974: 156–8, table 1; Bailey 1995: appendix 1). For comparison, at the 1981 sections in Callendar Park, the base was 4.5m broad (Keppie & Walker 1989: 144).

The base of the rampart was completed with a levelling layer, C1004, identified in microstratigraphic units S118.D, S121.C and S125.C (Gardner 2021: 20–1, 23, 60–3, 67–8, 75–6, figs 21, 24, 28, tables A1.13, A1.15, A1.18). This was a deposit, up to 0.10m thick, of red-brown gravely silty loam, which, like the bedding layer C1014 beneath the stone base, contained a mix of articulated chunks of A and B horizons. It also included some cultural material, such as angular charcoal fragments, again suggesting it was at least partly sourced from spoil and waste accumulating on the building site. Depending on how operations were sequenced, this could have derived from levelling operations, construction of the military way, or the top layers from the ditch excavation. Like the bedding layer, it was either already wet when dumped, was deliberately wetted during construction, or heavily rained on. This deposit was spread in and around the uneven stones of the raft to provide a level surface, but did not extend over the kerb stones. Here, the top of this levelling layer was mostly flush with the level top of the kerbs, which may suggest that the kerb stones were levelled to provide a level marker plane. As at other sections, however, especially in the eastern part of the Wall, some larger stones in the rubble raft protruded above the kerbs; whether intentional or not, these helped to key together stone base, levelling layer and turf superstructure, and militate against horizontal slumping (Romankiewicz et al 2020a: 125). Thin sand lenses were noted during excavation at 72 Grahamsdyke Street in places on top of the coarser and dark-red levelling layer. Their targeted analysis in units S125.B and S126.E indicates that the sand was slaked with water, perhaps as an easy way to level out any significant unevenness (Gardner 2021: 23–4, 27–8, 75–8, figs 28–9, tables A1.18, 1.19).

RAMPART SUPERSTRUCTURE

The rampart superstructure was constructed on top of these various preparation measures and base layers. It comprised three elements: a core and two cheeks built up directly over the north and south kerbs.

During excavation it was immediately noted that the core was constructed of laid turf blocks, a somewhat surprising observation given the location of the trench well to the east of Watling Lodge – a point we will return to. Four courses of turf blocks were documented, reaching a total maximum height of 0.35–0.40m; each course varied in height between 0.08m and 0.14m. The



Illus 5 Arrangement of turf blocks at different lifts, and keying of cheeks into core, at 72 Grahamsdyke Street and Callendar Park, Falkirk. Inset: construction layout of diagonal arrangement. (© B Russell, T Romankiewicz, J R Snyder, G Bailey)

colouring of these turf blocks – ranging from light white-grey, to mid grey-brown, to dark red-brown – also enabled the joints between them to be plotted in plan (Illus 2). This revealed their arrangement, which is of particular interest because they were placed diagonally, at around 45 degrees, rather than perpendicular, to the long axis of the rampart (Illus 5; some 10% variation in these angles seems accidental, likely caused by irregularities in turf block dimensions). Each course also seems to have been oriented perpendicular to the one below it, creating a cross lattice pattern with the course below and above. Blocks were placed slightly off-set to the ones beneath them so that as few vertical joints as possible aligned between courses (Illus 5 inset sketch plan). This is the first time that such systematic placing of turf blocks in an oblique arrangement has been noted in a Roman turf structure but not the first time that it has been encountered – as will be discussed below. We have since recorded similar oblique arrangements during our involvement in excavations in 2021 at High Rochester, Northumberland, and have been made aware of comparable evidence from Carlisle (William Hanson pers comm).

While the turf blocks of the core varied in colour, the material of the cheeks was a strikingly consistent light white-grey where preserved in situ – the same colour as the very palest of the turf blocks used in the core and some of the off-cuts in the bedding and levelling layers for the stone base (compare photos in Illus 2 & 5). This homogeneous colour made identifying joints between elements in the cheeks difficult during excavations, as well as characterising the exact material used in these cheeks. There were none of the 'black or red lines' that would have suggested turf use, only fine red spots throughout the material, some forming vertical lines (eg S110.A). Only in the south cheek could horizontal breaks between blocks of material be noted, not visually, but by material peeling off in corresponding horizontal planes during careful removal. This indicated the use of 'lifts' of material 0.12–0.15m apart in height. Similar breaks perpendicular to the long axis of the rampart and representing vertical joints between blocks were also noted in the south cheek. Both joints and lifts were targeted for micromorphology sampling (nos S103–S110) discussed below. The north cheek was too degraded – and mostly collapsed to the north – to allow similar observations to be drawn.

What could instantly be noted about the cheeks, however, is that they were keyed into the diagonally arranged turf blocks behind them, with their rear sides angled to form a saw-tooth join with the core (Illus 5). This meant that the cheeks and turf blocks of the core interdigitated between courses and that these elements were constructed together (Illus 6c). In plan, this was visible by notches cut into the back of the cheek blocks. The sections revealed that this interlinking of cheek and core could be quite substantial in places, with light cheek material stretching 0.20–0.30m into the dark core and vice versa, creating an interleaved pattern in section (Illus 3, S127.C and Illus 7a & c, S104.A, eg Gardner 2021: 82).

THE MATERIALS OF THE RAMPART

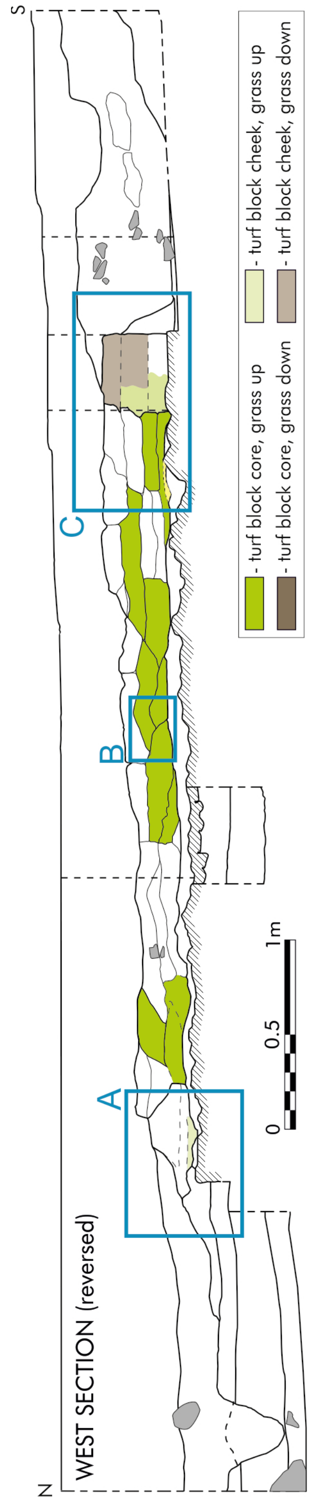
The core of the rampart, the cheeks, the interfaces between the two, and the collapsed and eroded material to the north and south were also sampled for micromorphological analysis. The key observations from this analysis reveal details about the sourcing and preparation of the materials of the core and cheek.

A total of eight slides from the core, C1001, demonstrate that the turf blocks used in this part of the rampart were sourced from grassland developed on glacial tills of the sort of acidic, sandy-silty subsoil present on site. Some of the turf blocks had eluvial characteristics, indicating podzol formation with the washing of fines and leaching of heavy metals from the mineral component into lower horizons. Their iron-rich nature suggests a generally wet environment in which the grass grew, with highly labile metals moving in solution through the groundmass of the soil.

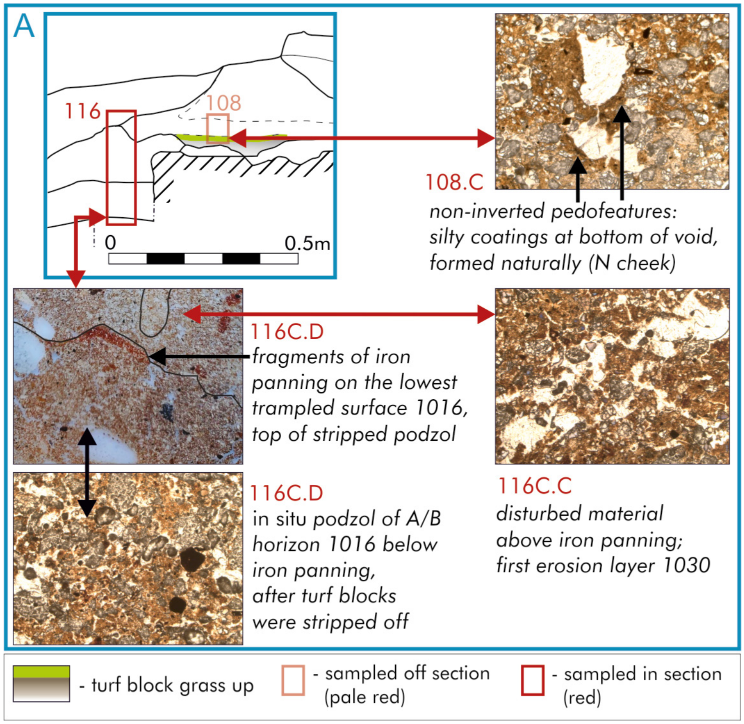
The turf blocks for the core were all cut from the grass level downwards and contain O horizons (albeit only traces thereof), A, and sometimes also B horizons, which can be distinguished microscopically by their principal pedological features (detailed below). There were no turf blocks containing just B-horizon material, a phenomenon noted for the turf fort ramparts at Vindolanda and interpreted there as evidence for double-cutting – that is, cutting two layers of turf blocks, one beneath the other, where the second block then only contained lower soil and some root matter (Russell et al 2021: 187, table 2, 193, fig 10, 201–2).

Due to the relatively dry and acidic preservation conditions at Laurieston, no O horizons were visible at macroscale and even under the microscope they could only be confirmed by dark traces of surviving plant matter from the compressed original grass and root matter (eg S104.C, Illus 7c), as well as by a thin and disparate layer of long- and short-celled phytoliths on the top crusts of A horizons (Illus 6c & 7c). Some of these phytoliths, silica-lined skeuomorphs of the grasses’ cell structure, are easier to spot as they appear bright red, resulting from a residual coating of relict organic matter that had been impregnated with iron (eg S129.C, Illus 7c). All of this explains why the characteristic ‘black lines’ of bands of compressed organic matter usually indicating turf were not visible during excavation. However, it also corroborates why, during careful excavation, it was noted that blocks tended to peel off from each other along certain planes, with the relict O horizons forming a cleavage plane between individual turf blocks. Several turf blocks also showed signs of multi-lamination in their O/A-horizon zones under the microscope, which is usually thought to indicate overgrazing and poaching of the original ground surface by livestock (eg S118.B and S119.A, see Illus 7b); this might further explain the limited survival of O-horizon material; in other words, the vegetation was already partially denuded prior to construction. Typically, the A horizons showed a drop in phytoliths and a corresponding increase in fine mineral material, including fine sands, silts and some clays. Their granular microstructure resulted from earthworm and other soil fauna activity. The A/B and B horizons generally contained only minimal traces of organic matter and phytoliths, and had a more blocky microstructure with less disturbance from soil fauna activity (compare differences between an inverted O horizon of one turf block on top of the A/B horizon of another one below, with a sharp boundary between these, S106, Illus 6c).

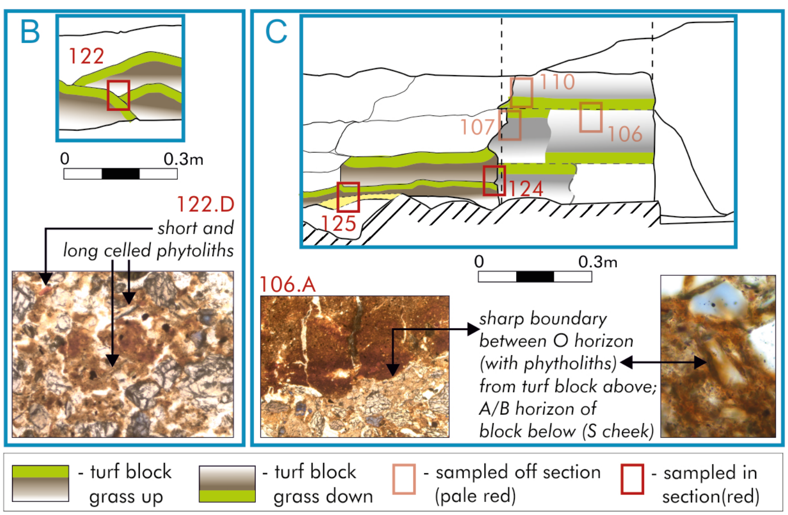
The laying of the turf blocks showed a curious pattern, in those areas where analysis was possible. Unlike elsewhere along the Antonine Wall or at Vindolanda, the turf blocks at 72 Grahamsdyke Street were not always laid inverted, that is ‘grass-down’ as for example recorded for Croy section no. 11 (GAS 1899: 73, 76) or Balmuildy Road (Henderson in Keppie 1976: 66; compare Russell et al 2021: 192, fig 9c, 194). They were also not laid consistently ‘grass-up’, nor stacked grass-on-grass then soil-on-soil, as for example suggested by macroscopic observations at Bonnyside in relation to the military way, where its cobbles stratum sat directly on two to three courses of laid turf (Keppie 1976: 63; compare Hanson & Maxwell 1983: 82–3). At 72 Grahamsdyke Street, the builders seem to have alternated the orientation of the turf blocks across the width of the Wall, but in a seemingly regular pattern (compare Illus 6a & 7a for variation of orientations across core and in cheeks). Given the lack of visible distinction between the soil horizons as surviving, the orientation of these blocks can only be confirmed in thin section, and some indicators are clearer than others. The easiest way to assess orientation is by identifying sharp boundaries between soil horizons to distinguish separate turf blocks (eg S106, Illus 6c) and then characterising the positions of O, A or B horizons within each block (S188.A–B, Illus 7b; S104.B–C, Illus 7c; compare Holst & Breuning-Madsen 2013: 244–5). Another but more ambiguous method is to pinpoint markers of soil orientation such as mineralisation or eluviation crusts and coatings within voids as either non-inverted (ie gravitationally oriented as naturally formed, S108.C, Illus 6c) or as inverted (S104.C and 120.B, Illus 7b–c). In those areas where the preservation permitted such analysis, the builders seem to have laid some turf blocks systematically grass-up, others consistently grass-down. These positions were roughly repeated course by course, resulting in vertical stacks of turf blocks



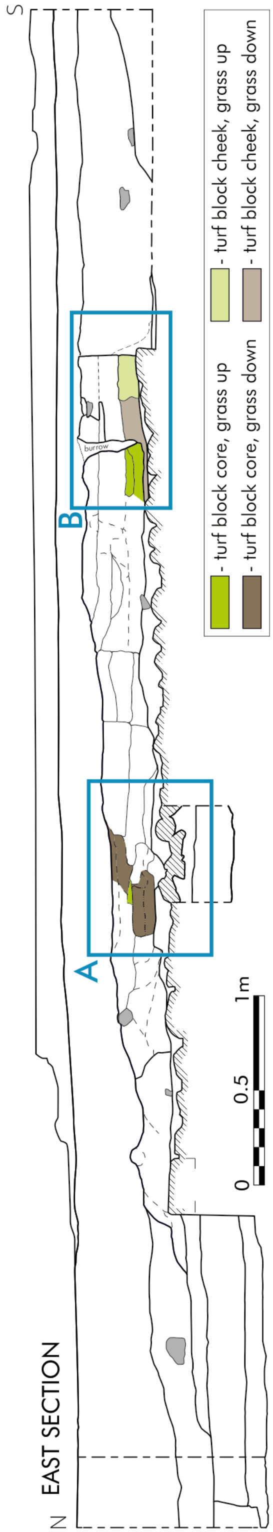
Illus 6a West section with location of turf blocks laid grass-down or grass-up (as analysed). (© B Russell, T Romankiewicz, J R Snyder, T Gardner)



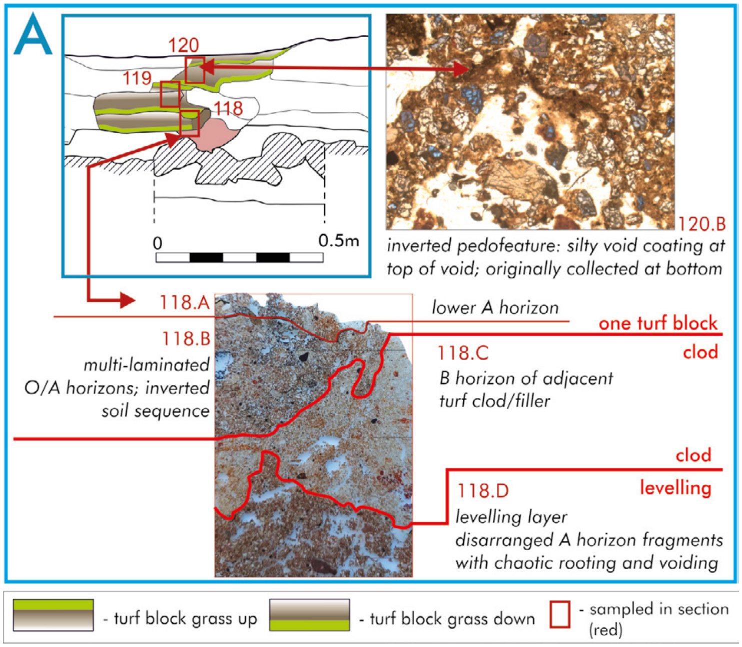
Illus 6b West section: details from micromorphological thin sections in area A: S116C.D at 1× and 40× magnification; S116C.C at 40× magnification; S108.C at 40× magnification. (© B Russell, T Romankiewicz, T Gardner)



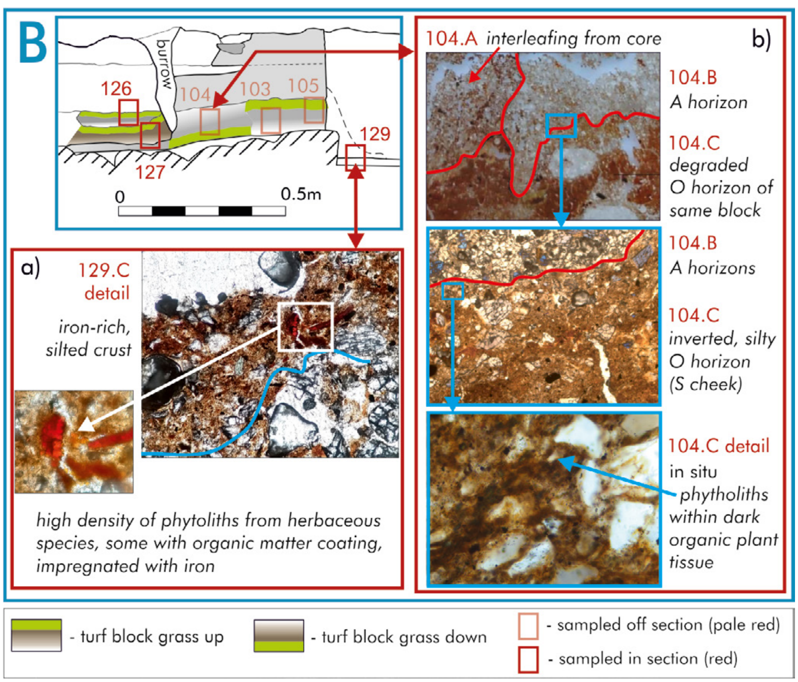
Illus 6c West section: details from micromorphological thin sections in area B: 122.D at 100× magnification; in area C: 106.A at 1× and 400× magnification. (© B Russell, T Romankiewicz, T Gardner)



Illus 7a East section with location of turf blocks laid grass-down or grass-up (as analysed). (© B Russell, T Romankiewicz, J R Snyder, T Gardner)



Illus 7b East section: details from micromorphological thin sections in area A: S118 at 1× magnification; S120.B at 40× magnification. (© B Russell, T Romankiewicz, T Gardner)



Illus 7c East section: details from micromorphological thin sections in area B: S129.C at 40× and 400× magnification; S104 at 1×, 40× and 400× magnification. (© B Russell, T Romankiewicz, T Gardner)

oriented in the same direction when viewed in section (Illus 6a & 7a). This alternation between up and down is even more striking within the cheeks, where despite their narrow width, two blocks seem to have been laid side-by-side but with different orientations (Illus 6c & 7c). From a first glance, this patterning appears to have been a deliberate decision and turf block orientation was neither an accidental result of how blocks were picked up and laid down, nor was there confusion about which side had been the vegetated surface, despite the truncation of the O horizons. However, why this stacking was undertaken is not clear; various suggestions can be brought forward but none explains this observation conclusively. Given the remaining ambiguity in the interpretation of inversion markers and the apparent variation of orientations along the Wall as noted above, more systematic microscopic analysis of different sections is needed.

Unlike at the fort ramparts at Strageath or Vindolanda, and numerous others elsewhere (Russell et al 2021: 169), there is no evidence here for lacing courses – layers of wooden sticks or more substantial timber offcuts laid in earth, which are also referred to as 'strapping' or 'lacework' (Frere & Wilkes 1989: 15–27; see also at London: Dunwoodie et al 2015: 45–7; Strasbourg: Kuhnle 2018: 154–8). This might simply be because the rampart at 72 Grahamsdyke Street is not preserved to a sufficient height. These lacing courses, where found, are typically 0.20–0.50m apart (Russell et al 2021: 175–7), and it is possible that here the first lacing course was located over 0.40m above the stone base (compare evidence of lacing course 0.60–0.70m above the raft at Strasbourg, see discussion in Russell et al 2021: 177). However, no lacing courses have been noted anywhere else along the line of the Antonine Wall, even where it is preserved to a greater height (compare single note on 'some wood' within the 'thick deep black … [bottom layer with] a dense peaty character' at Croy no. 11, GAS 1899: 73–4). We also found no evidence for the use of earth mixes to level up courses of blocks (on this practice at Vindolanda, see Russell et al 2021: 197–9). Occasional patches of earth and disoriented A-horizon material, however, suggest that loose soil and clods of turf were used for ad hoc patching during construction (eg S118.C or S119.A, Illus 7b; compare patching at Vindolanda, Russell et al 2021: 170, 180, 182, fig 7, 183, table 1).

The material from the cheeks – which appeared so different during excavation – was analysed in eight slides (Table 1). While the material could not be identified during the excavation, the micromorphology confirmed that the cheeks were also built of turf, showing as intact, articulated soil blocks (eg S106.A is separate turf block from unit S106.B–C, Illus 6c) and as layers of high phytolith concentrations that represent the former vegetation (eg S104.C, S110.B, Illus 7c; Gardner 2021: 8–9). This was a genuine surprise. The field observations had favoured the interpretation of blocks cut from clayey subsoil – 'clay blocks' – without associated A and O horizons; their clay-rich nature was apparent, but the material had peeled off in blocks of regular courses, horizontally as well as in vertical sections (see Illus 2 & 4 photogrammetric record). The thin red spots observed, suggestive of root channels, were confirmed as such by micromorphology as preserved organic root matter stabilised by iron mineralisation, hence the red colouring. Plant fibres, as typically added to mudbricks or cob mixes, would be expected to have a lower iron intake signature, primarily because they tend to be added as drier material. Fibres from above ground plant growth (such as hay or straw from grasses and sedges) would be expected to be larger, to shrink less, and to contain more identifiable phytoliths.

While analysis now shows that core and cheek are both of the same general type of material – turf – it also shows that the striking colour difference between them is due to different pedogenetic (or soil formation) processes. The turf used in the cheeks developed on a clay/sand-rich but silt-poor soil, likely from a water meadow in an alluvial zone (on average 40–45% sand, 35% silt, 20–25% clay, qualitatively assessed), compared to the glacial tills of the core (40% sand, 45–50% silt, 10–15% clay). Fluvial bedding layers in the cheek turfs reveal the waterborne origin of much of their sediment, while remains of sponges (spicules) and single-celled algae (diatoms) also point towards periodic flooding of such grassland. Furthermore, their O horizons are even thinner and hence more degraded than the already poorly preserved O horizons in the core turf blocks; thus the characteristic dark O horizon lines have become invisible for macroscopic recognition in the field.

As noted macroscopically, the turf blocks of the cheeks and those of the core were interdigitated, with the rear of the cheek turf blocks cut at an angle to receive those of the core (Illus 5). The thin section analysis showed that any gaps between the blocks of core and cheek were patched with loose soil or turf offcuts (eg S126.C, Gardner 2021: 24, figs 29, 79).

EVIDENCE FOR EROSION AND COLLAPSE

While sampling of the rampart itself provided important insights into its construction, sampling immediately to the north and south of it revealed evidence for its erosion and collapse, both during and at the end of its use-life.

Along the front of the base of the south cheek, finely eroded cheek material formed a thin layer, noted in the field as context C1019. Micromorphology confirmed this as the result of periodic waterborne but low-energy erosion of fines, particularly clay (unit S129.B) – in other words, rainwater washing the fine silt and clay particles off the cheek surface, but not compromising overall stability (Gardner 2021: 2, 9, 85, table A.1.21). Context C1019, therefore, built up gradually over time, likely during the early use of the Antonine Wall. This material fell onto the top of a compacted surface (C1013, unit S129.C; compare S132.A underneath the stone base; Gardner 2021: 25–6, 83–5, figs 32 & 33, table A1.21) that had formed a silted crust and iron pan, containing notable amounts of phytoliths (Illus 7c). This evidence suggests that this surface had perhaps started to regrow after the soil material C1013 had been backfilled into the construction cut C1025. This would indicate low usage of the area immediately south of the rampart in the early days of the Wall, and that at least one summer, but likely more, may have passed for vegetation to re-establish before the cheek started to erode (one to two growing seasons estimated for Danish barrow sites, Holst 2013: 238). Alternatively, strips of turf could have been laid on top of the backfill after construction to consolidate this area in front of the south cheek against wear. In any case, the thin section shows no sign of puddling, in the form of lamination or diatoms, indicating that very little water pooled against the rampart base; and what occurred was likely soaked up by said vegetation or drained downslope through the stone base. There seems then to have been further and more substantial erosion represented by context C1029 and later context C1026, and analysed as units S128.A–B and S129.A, on top of the thin erosion layer C1019 unit S129.B; the first of these, C1029, survives against the original south face of the cheek up to a height of 0.30m (Illus 3 & 4). The placing of sample S128 inadvertently showed that about 5cm of the original south cheek face was lost (Illus 3). Although intended to target the 50mm-wide sample box onto the interface between the projected face of the cheek and collapse in front of it, the thin section actually revealed that this area only contained erosion (C1026/C1029) – the eroded face of the cheek must lie just beyond the left-hand edge of the slide.

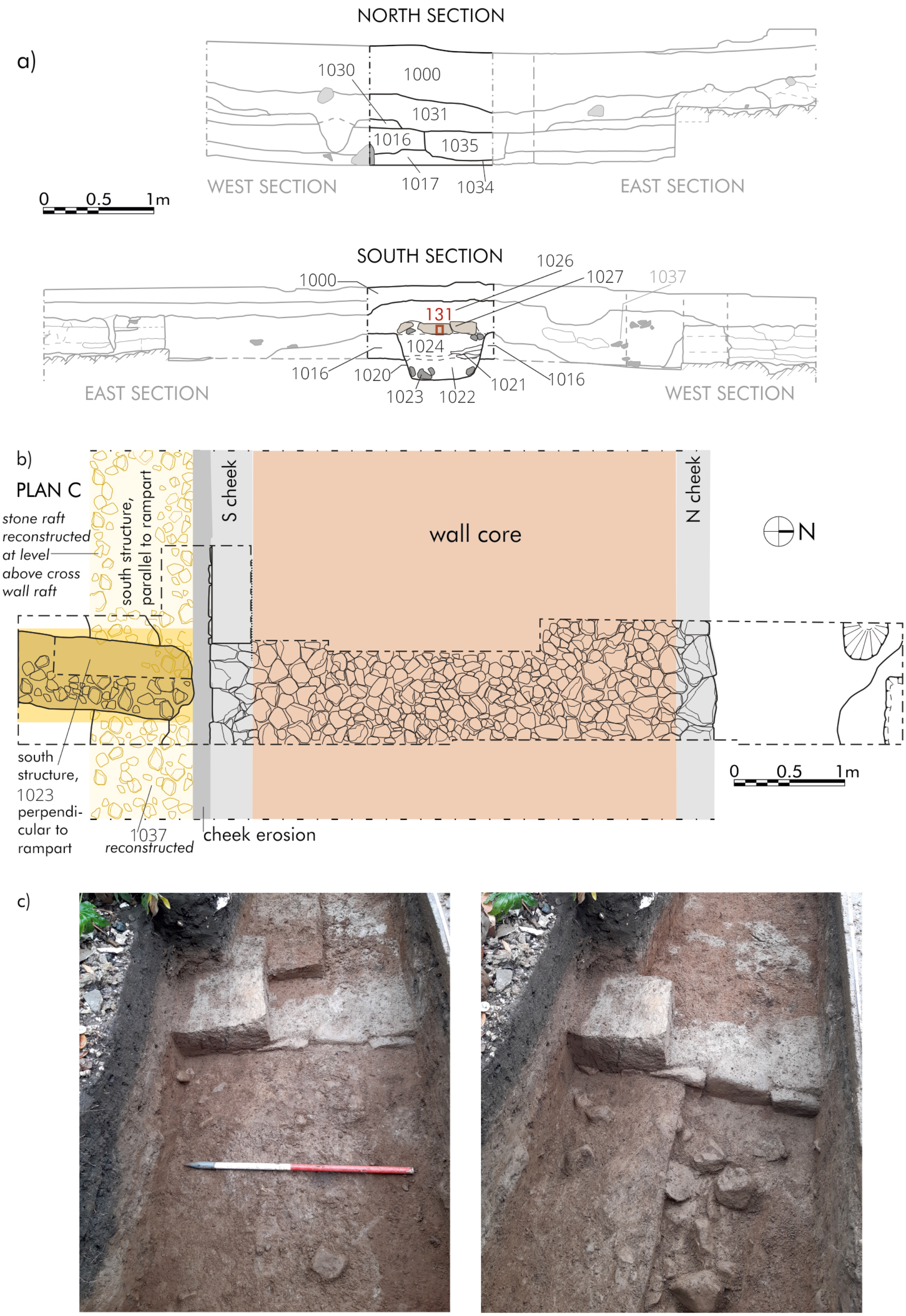
The north edge of the rampart collapsed more dramatically than the south, slumping across the berm and downslope towards the ditch. Samples S114, S115 and S116 were arranged across this collapse. Thin sections S116A–C and S114 reveal that the north cheek of the rampart was eroded initially in the same way as the south cheek, with fines washing off the face. A sequence of eroded sediments with signs of periodic weathering and iron panning on top of each individual surface were identified within 0.10–0.15m of horizontal layer C1030 (units S114.B/C, S116B.C, and S116C.C/D). These sandy/clay deposits had formed gradually on top of the de-turfed ground surface C1016, indicating that this erosion was also gradual, not catastrophic, comparable to similar slow deterioration C1019 and C1029 to the south. These layers of trampling suggest frequent activities on the berm, perhaps as part of maintenance works, or even a phase of consolidation or repair (Illus 6b S116C.C; Gardner 2021: 9, 15–16, 18–19, 50–2, 56–9, figs 15–16, 19–20, tables A1.9, A1.11–12). More substantial deterioration seems to have occurred later, with cheek material C1008 spreading off the kerb and downslope (S116B.A–B), destabilising some redder C1007 and paler C1009 core and/or cheek material originally behind and below C1008, which is indicative of some general northward slumping of the rampart (Illus 3; S108.A–B: disarticulated collapse, S108.C in situ articulated N cheek, Illus 6a & b; Gardner 2021: 13, 45–6, fig 12, table A1.7). Individual turf blocks that had tumbled out of the core could be distinguished in thin section from those of the cheek, C1008, due to their different source material (Illus 4; eg S116A.A–C/E–F from cheeks and core compared to S116A.D trample after initial erosion, probably associated with maintenance or repair, Gardner 2021: 17–19, 53–5, figs 18–20, table A1.10).

STRUCTURES TO THE NORTH AND SOUTH

As well as the evidence for erosion and collapse, excavation to the north and south of the rampart identified other structures relating to the Antonine Wall. To the north, in the area of the berm, the original, de-turfed ground surface C1016 and lower cultivation soil C1017 were cut into by two pits, C1034 and C1032, perhaps defensive *cippi*. These were probably cut early in the life of the Wall, with C1034 likely pre-dating C1032 (Bailey et al 2021; Illus 8a: N section).

To the south of the Wall, a more complicated situation was uncovered, which was difficult to disentangle in the narrow trench. Pre-Antonine cultivation soils, C1016, were again reached here and cut into these was a broad gulley, C1020, about 0.65m wide and 0.40m deep, running north/south; the base of this was filled with sandstone cobbles to form a wall footing, C1023. This gulley ran up to the south face of the Wall's rampart, with the structure it supported then seemingly turning to the west and possibly east, along the face of the Wall, with the stone raft for its footing appearing to sit at a higher level here (Illus 8a: C1037 in south section; Illus 8b). These features most likely represented the wall of a building, with the wall along the rampart needed as support for a low roof structure (Illus 8b & c). Although its foundation slot left a gap of 0.10–0.30m in front of the cheek of the rampart, the wall of the building may have extended beyond this to abut the Wall's south cheek. Turf blocks were visible in the south section of the trench, C1024 and C1027, corresponding to the remains of the superstructure of this small building (Illus 8a). Slides S109 and S131 confirm that the wall built into this gulley was also constructed in turf (Gardner 2021: 9, 48–9, table A1.8). The slot itself was filled with turf similar to that used in the core of the Wall's rampart (S109.B), with blocks laid grass-down, likely as a turf footing placed within the foundation slot. This was then overlaid by turf blocks, grass-up (unit S109.A); both turf blocks were from the same source as those used in the cheeks, showing some compaction, applied either during construction or by the load of the wall that these turf blocks represent (see also S131.A; Gardner 2021: 9, 83–5, table A1.21).

The foundation gulley for this secondary building cut into the earlier erosion deposit C1019 and into the eroded material C1029, since the steep angle remaining of the latter seems less likely to represent the original settling of collapse and more likely a truncation during these later building works (Illus 3 & 4). However, this building also pre-dated the final collapse of the Antonine Wall, since thicker erosion deposits C1026 cover its foundation cut and fill. Use of turf material similar to the cheeks and fragments of black-burnished ware recovered from among the stones in the bottom fill of the slot suggest a Roman date; the large sherd sizes and crisp breaks render it unlikely that the material was residual and redeposited at a much later stage. This turf building, therefore, seems likely to have been constructed against the southern side of the Antonine Wall in the Roman period, but



south structure at level of PLAN A *looking north*

south structure at level of PLAN B *looking north*

Illus 8 (previous page) (a) South and north sections as relating to adjacent parts of east and west sections. Samples are identified by three-digit numbers in red, contexts by four-digit numbers in black; (b) reconstruction in plan of possible location and extent of structure to south, with stone raft C1037, for wall parallel to rampart sitting at higher level in plan than stone raft C1023 for wall perpendicular to rampart; (c) pre- and mid-excavation photographs of south structure. (© B Russell, T Romankiewicz, J R Snyder)

it was not associated with the original rampart construction phase. It may have been an installation at a later stage or formed part of the *vicus* stretching west from Mumrills fort (Bailey 2021: 357). Remains of collapsed turf recovered from the 2019 excavations on the south side of 72 Grahamsdyke Street (Trench E, Illus 1; Gardner 2020: 7, 10–11) may relate to this same structure or perhaps a similar building located to the east of it and again immediately south of the Wall (see Bailey 2021: 355–71). The recovery of an almost intact Roman leather shoe sole underneath the turf collapse here again supports a Roman date for these structural remains.

IMPLICATIONS: THE 72 GRAHAMSDYKE STREET SECTION IN ITS WIDER CONTEXT

The discussion of this well-preserved section of the Antonine Wall shows the importance of applying micromorphological analysis to turf-built structures. Our work demonstrates how much information can be gleaned even from such an ephemeral building material and how much can survive even in non-waterlogged conditions (compare Romankiewicz 2019; Romankiewicz et al 2020b; Russell et al 2021). Since this is the first geoarchaeological study of the Antonine Wall, the applicability of the results to other Wall sections cannot be ascertained. While further such sampling and analysis of different Wall sections is imperative for enhancing our understanding of this UNESCO World Heritage site as a whole and its conservation management in a changing climate, more such work is also vital in order to test whether our interpretations apply more widely across the Wall. A review of other excavated evidence suggests that such testing could confirm more expansive use of turf east of Watling Lodge, and thus a more homogeneous use of building materials than previously anticipated (Table 2; contra Romankiewicz et al 2020a: 129–30, then based on previously excavated, macroscopic evidence only).

THE LEVELLING OF THE BASE

Much of the groundworks undertaken prior to, and in connection with, the laying of the stone base at 72 Grahamsdyke Street finds parallels elsewhere along the Wall, east as well as west of Watling Lodge. The stripping of turf prior to construction is a practice noted at nearby Beancross, for example, but also west of Watling Lodge (Bailey in Keppie et al 1995: 613; for summary, see Romankiewicz et al 2020a: 124–7). The turf cut from beneath the rampart's footprint was seemingly used in the structure itself and indeed estimates of the quantities of turf required for the rampart of the Antonine Wall have indicated that much of it could have been sourced, at least in terms of the basic quantities required, from a strip of land as wide as the distance between the ditch and the military way (Snyder et al in press).

Evidence for a bedding layer underneath the stone base seems to have been documented at Balmuildy Road, north of Bishopbriggs, where careful examination of the construction sequence showed that the Roman builders here seem to have taken an almost identical approach to that observed at 72 Grahamsdyke Street. At Balmuildy Road, the northern part of the ground had been levelled by a 'shelf … cut into the subsoil' interpreted as 'evidence for terracing of the slope to secure a level surface for the stone base' (Henderson in Keppie 1976: 66; compare terracing at Garnhall Farm and discussion of Balmuildy Road in Romankiewicz et al 2020a: 125). However, as at 72 Grahamsdyke Street, 'the shelf was not utilised' to receive the stone base directly; instead, after the turf had been stripped and the terrace cut, the shelf ‘was filled with a grey sticky silt, and the stone base laid on top’ (Henderson in Keppie 1976: 66). This was presumably done for similar reasons as at 72 Grahamsdyke Street, to improve stability and drainage, because the clayey subsoil at Balmuildy may have been too impermeable and compacted to press the stone base into its surface. The silty infill raised the top of the stone base to ‘only marginally below the original subsoil level’ (Henderson in Keppie 1976: 66) and what may seem a cumbersome replacement of the original topsoil with more topsoil was clearly an intentional operation – to level the ground and presumably to avoid slippage and increase drainage. Similar conclusions could be drawn for St Flannan’s Church, Kirkintilloch, where a bedding layer of turf and topsoil might have been introduced to raise the original, sloping ground by about 0.10–0.15m underneath the northern quarter of the rampart (Speller & Leslie in Dunwell et al 2002: 281, 283; illus 17). Elsewhere, the stone base is usually identified as being laid directly upon the subsoil but without microscopic investigation the accuracy of this observation is difficult to assess (see Romankiewicz et al 2020a: 124, 127, and especially where excavators comment on the careful levelling of the stone base).

The Balmuildy Road section also provides a good parallel for a levelling layer on top of the stone base, with Henderson noting that ‘a layer of yellow clay’ was packed between the stones of the base to level off its ‘inequalities’ (Henderson in Keppie 1976: 66). At St Flannan’s Church again, the west-facing section shows a substantial soil layer immediately on top of the stone base, levelling off the slightly sloping stone base with on average 0.15m of material (Speller & Leslie in Dunwell et al 2002: 281–3; illus 17). East of Watling Lodge, Steer notes for the section at Polmont Park West, surviving *c* 0.25m (= 10in), that ‘[w]hat little remained of the superstructure consisted of the natural sandy subsoil with the random addition of a few turves’ (Steer 1961b: 322). This description would fit a levelling layer like that at 72 Grahamsdyke Street. At Callendar Park, layer 7 in the western trench section (marked ‘M’, planned at 0.10m above stone base) could be interpreted as providing a similar levelling (Bailey 1995: 581, illus 3). More recent work at the Old Bindery, Falkirk, in 2003 (Section E) showed a levelling layer for the stone base, clearly containing turf, below the main earth core (Bailey 2021: 313).

Without further analysis it is impossible to verify the composition of the layers identified in these earlier excavations and whether the material surviving on top of the stone base represented levelling layers or the remains of a mixed-earth superstructure (Table 2). Even at 72 Grahamsdyke Street, this deposit is noticeably varied, containing silt- and clay-rich turf offcuts, as well as sand and gravel.

The micromorphology of the various make-up, bedding and levelling layers identified at 72 Grahamsdyke Street, underneath and on top of the stone base, provides some indications of where these materials might have been sourced. The earth in both layers contained a mix of A and B horizons, as well as cultural material, notably mortar and charcoal. In contrast, the soils of the turf blocks were considerably more sterile. The presence of both A- and B-horizon material in articulated chunks within the layers suggests that offcuts and leftovers of turf blocks were reused. Their most likely source is the construction of the adjacent section of rampart superstructure: anything broken up, not needed, or trimmed off blocks to make them fit while building the turf wall was simply thrown ahead, either to be integrated into the next stretch of bedding layer below or levelling layer above the stone base. If this reconstruction of the process is correct, it would indicate that the stone base, at least in this part of the Wall, was constructed just in advance of the rampart superstructure and presumably in short segments rather than long stretches. This has already been suggested based on evidence at Callendar Park, where it was proposed that turf was stripped immediately in advance of the building of the stone base and turf offcuts were thrown onto the ‘advancing foundation’ (Bailey 1995: 585). Additional soil within this matrix could have come from the wider construction site and any associated labour camp, given its contamination with cultural material. Whether spoil from the ditch was used would depend on when within the sequence the ditch was excavated; this could be tested by sampling the original ditch edges to determine their soil characteristics in comparison with the matrix of the bedding and levelling layers.

The role of the stone base in drainage has been examined in detail elsewhere (Romankiewicz et al 2020a). It would have facilitated the draining of water from one side of the rampart to the other, together with the built culverts set into the base at regular intervals. Its porous structure would also have helped to manage moisture levels within the rampart itself. Water would have percolated down the turf core during the Wall's use-life when being rained upon (on this point, GAS 1899: 127). The gravelly-sandy deposit (C1004) on top of the stone base at 72 Grahamsdyke Street, though primarily a levelling layer, would have facilitated this internal drainage; in combination with the stone base itself it would have allowed water to be gathered up and drained away at the base of the rampart and would have reduced, but not prevented, capillary uptake by the wall (compare GAS 1899: 127). Extensive indicators of water movement and repeated draining of this layer, as for example noted in unit S118.D (Illus 7b) and within the sandy bedding layer (see above), also suggest that water was flowing freely through the deposit, washing silts and clays into voids within the groundmass. A clay-rich levelling above the stone base as found at Balmuildy (see above) would have been less advantageous for such aspects, but this may simply represent the easiest solution from what was available on site there. About 500m to the west of the Balmuildy Road section, at Easter Balmuildy, 'occasional flecks of turfy material' within a soil matrix above the stone base were used instead, seemingly for a better draining levelling layer (Keppie 1976: 67).

TURF SOURCING

The sequence of made-up ground, bedding and levelling at 72 Grahamsdyke Street and other Wall excavations shows the detailed planning involved in creating a stable footing for the turf wall (Table 2; compare Romankiewicz et al 2020a: 125). The materials for the superstructure were selected with equal care and used with consideration. This also potentially explains certain features noted macroscopically at various other locations along the Wall.

Perhaps the most intriguing result of the micromorphological analysis at 72 Grahamsdyke Street is the fact that although the entire rampart was built in turf, the blocks in the cheeks were sourced from a different location to those in the core. The latter were cut from grassland on glacial till, probably in the immediate vicinity of the Antonine Wall; they may well come from the footprint of the structure itself, as noted above. The evidence for erosion and periodic sedimentation within their topsoils is indicative of trampling, likely a result of intensive grazing, perhaps overgrazing in this area, but the truncation might also relate to heavy footfall in advance of, and during, construction. The fact that the blocks were not double-cut also suggests that the exploited grassland was reasonably well-draining, with the roots of the grass reaching no more than 0.15 to 0.20m; the thick and deep root matter needed for double-cutting typically only develops in wetter locations (Milek 2012: 121–3; for the concept and examples of double-cut turf blocks at Vindolanda, see Russell et al 2021: 193, fig 10).

The turf used in the cheeks was very different from that of the core, both macroscopically and microscopically. Since turf suitable for construction was evidently available in the vicinity of the Wall, the decision to bring the turf blocks for the cheeks from elsewhere requires an explanation. One possibility is that this turf – formed in a wetter alluvial zone – was considered more suitable for moisture management. The cheek material had a notably high-sand/high-clay composition, which would have allowed it to drain much more quickly than the silty core, but also offering greater cohesion for each block and between blocks due to the frequent clay particles. Alternatively, the builders may have found the turf from this source easier to cut and stack neatly – to ensure a tight join between blocks – than the looser turf material used in the core. Where exactly this sandy-clayey turf came from cannot be precisely verified but north of the line of the Wall, on the Carse of Forth, would seem likely. Keppie identified a band of so-called ‘brick clay’ mixed with sand and gravels, coinciding with a 6–7km stretch from 400m west of Watling Lodge to Polmonthill, from which the cheek material could have derived (Keppie 1976: 78; compare Gardner 2020: 10). This suggests that considerable effort was taken to source the right type of turf for particular parts of the rampart; the builders knew what they were looking for, even if we cannot now be sure of the criteria on which they were judging the material.

Importantly, this pattern of different turf blocks in core and cheek has been described elsewhere. Field observations at Croy Hill and Bonnyside noted the use of turf blocks in the cheeks that were paler and/or redder than the turf in the rampart core, a detail that has recently been reinterpreted as evidence for deliberate construction strategies (Romankiewicz et al 2020a: 133–6). Excavation at Tayvalla had identified the selection of better-quality turf for a repair of the original turf cheeks (Bailey 2021: 19). East of Watling Lodge, evidence at Inveravon suggests a more clay-rich material for the cheeks, interleaved with projecting brown turf blocks from the core (Dunwell & Ralston 1995: 530–1, illus 6). This matches the way in which the turf cheeks and turf core were tied together at 72 Grahamsdyke Street. Steer found leached ‘turf-work’ cheeks *c* 0.45m (= 18in) wide, at his section ‘A’ some 120m west of Mumrills, consisting of ‘whitish-grey [material], but its layered structure was clearly visible in places’ (Steer 1961a: 94). At Bantaskin, Keppie described 0.6m of turfwork surviving in both cheeks as ‘greyish lumpy clay, [but] identifiable … by its colour and texture’ and occasional ‘horizontal rusty-brown lines’. This was very different from ‘the remainder of the core’, which was ‘an orangey buff clayey soil … with some distinctive greyish patches [of] … turf blocks thrown in’ – and confirmed as distinct by unspecified environmental analysis (Keppie 1976: 71–2). At the Old Bindery in Falkirk, section E showed a red-brown sandy-loam core of up to 0.38m in height, retained initially by broad turf cheeks, interleaved with the core. These were subsequently replaced by what was described in the field as pale cream clay loam, laid as blocks along the faces to create a steep front at either side (Bailey 2021: 312–16, 350–3, figs 6.1, 6.4). On comparison with 72 Grahamsdyke Street, this now seems likely to represent silty-clay turfs. Similar keying of the cheek material ‘B’ into the core has been documented for Callendar Park (Bailey 1995: 581, illus 3, compare Illus 5 above). Bearing in mind Keppie’s statement cited here at the start (Keppie 1976: 78), Macdonald’s ‘wrought clay’ cheeks identified in various sections around Mumrills (Macdonald 1934: 87) or Steer’s identification of ‘stiff yellow clay’ for the cheeks just west of Mumrills fort (Steer 1961a: 94–5) might also actually represent compacted sandy-clay turf blocks (Table 2) – but only further analytical work could clarify this.

In terms of the Wall core, where this survived up to 0.40m, Macdonald suggested that ‘such stray patches of clay as showed themselves were probably accidental’ (Macdonald 1915: 120–1). It is possible that Macdonald had found remains of mixed levelling layers, similar to those noted at 72 Grahamsdyke Street and St Flannan’s. However, the depths of Macdonald’s deposits could also represent a similarly varied but turf-built core as at 72 Grahamsdyke Street, where turf blocks with poorly surviving O horizons alternated with white turf blocks that had not been needed for the cheeks. Had it not been for these white blocks, or very homogeneous reddish blocks surviving intact in the core (Illus 2), the general core matrix at 72 Grahamsdyke Street could have easily been interpreted as dumped earth – only micromorphology confirmed that all of this consisted of articulated turf blocks. A similar explanation may hold true for Steer’s observations of his two sections C and D at Hayworth Avenue immediately west of Mumrills fort, where he notes that the core consisted of a mixed brown sandy loam, surviving *c* 1.2m high (Steer 1961a: 94–5). It should be remembered that Steer only cleaned up sections previously cut by the developer, rather than excavating the core in plan. Excavations at 72 Grahamsdyke Street took down the core material gradually, in thin spits levelled across the entire width of the rampart and beyond, which thus readily revealed the otherwise quite ephemeral evidence of the turf blocks. Other instances at sites where 'occasional turf blocks' had been noted in the core may on reflection similarly present a turf-only construction (Table 2).

BUILDING IN TURF

Although the turf blocks in the core and cheeks at 72 Grahamsdyke Street were from different sources, they were carefully combined in the final construction. The placing of the core blocks in a 45-degree diagonal arrangement is a constructional detail not so far described elsewhere for a Roman-era turf rampart (Illus 5). However, the plan by Bailey of the trench at Callendar Park shows several turf blocks laid at a similar 45-degree angle in the eastern part of the core (Illus 5, 'E' in Bailey 1995: illus 3). Turf blocks at St Flannan's also show an oblique arrangement, at least for those blocks planned in detail, but in a less consistent pattern (Speller & Leslie in Dunwell et al 2002: 283, illus 17). Steer's section 'A', or Keppie's at Bantaskin, where they identify haphazardly laid blocks in the core, may only seem random if a pattern perpendicular to the long axis of the Wall had been expected (Steer 1961a: 94; Keppie 1976: 71–2). Placing the turf blocks of the core in this diagonal way allowed the cheeks, with blocks placed perpendicular to the long Wall axis, to be keyed together more satisfactorily with the core. This arrangement (Illus 5) avoided a sharp and straight juncture between the two structural elements that a perpendicular pattern for both would have created. Such a straight joint might have led to the cheek pulling away from the core (on this risk and possible evidence for it elsewhere, see Dunwell & Ralston 1995: 530–1; Romankiewicz et al 2020a: 136–7). By diverting the load obliquely onto the cheek rather than perpendicularly, the cheeks are less at risk of pulling away or shearing off at the joint, and in fact the oblique loading would help to interlock the angled joints.

The distinctive arrangement of the turf blocks of the core and the cheeks can also tell us something about the rhythm of construction. Since the turf blocks of the core and the cheeks interdigitated not only horizontally but also vertically, the turf blocks of the cheeks and core can only have been laid course by course (Illus 5, sketch plan inset). Some individual turf blocks from the core stretched quite far into the cheeks in places and vice versa – as visible in the south cheek in the east section in particular (Illus 3 & 5). Furthermore, the cheek blocks had their rear sides cut to receive the ends of the angled blocks in the core while offcuts or loose soil material were sometimes packed between cheek and core turf blocks (Illus 5; see 126.C, Gardner 2021: 79). All of this could only have been done if cheeks and core were constructed together. The builders must have had separate piles of turf blocks for the core and for the cheeks, and it is even possible that separate teams of workers focused on the different elements, especially since the turf blocks in the cheeks required on-site trimming and adjustment, unlike those in the core.

The turf blocks for the core and cheeks were seemingly also of different dimensions, albeit not in height. Where block dimensions could be measured, they were on average 0.1m high, but this measurement does not account for shrinkage from drying out immediately after cutting, as well as the effect of compaction from compression and eventual decomposition. This applies especially to the organic components, when built into the Wall. Such shrinkage cannot be easily quantified. Although of similar height, the blocks in the core were substantially longer than the compact ones used in the cheek. The latter could also not be accurately measured given the difficulties in separating individual blocks without colour differences; thanks to the colour variation of the blocks in the core, their average dimensions could be determined as 0.58m long × 0.33m wide. These are relatively long for Roman-era turf blocks. The Roman author Vegetius, writing in the late 4th or early 5th century, says turf blocks of 1.5 × 1.0 × 0.5 Roman feet, or 0.44 × 0.30 × 0.15m, are best suited to camp building (*De re militari* 3.8). In fort ramparts, a range of average sizes of turf blocks have been noted: 0.30 × 0.30 × 0.08m at Plantation Place, London

(Dunwoodie et al 2015: 47); 0.30–0.40 × 0.25–0.30 × 0.10–0.15m at Strasbourg (Kuhnle 2018: 154–8); 0.46 × 0.30 × 0.03–0.08m in the Flavian rampart at Strageath but up to 0.61m long in the Antonine I one (Frere & Wilkes 1989: 17, 19). At Vindolanda, the turf blocks observed in section have a median length of 0.26–0.31m and height of 0.06–0.08m, though some blocks extend to 0.68m in length (Russell et al 2021: 186–9, table 3, 200). The 72 Grahamsdyke Street turf blocks sit at the upper end of the range of dimensions noted here but their closest parallels come from a structure of broadly the same date also in Scotland: the Antonine I ramparts at Strageath. The smaller size of blocks, only 0.25m wide, noted for the cheeks at Laurieston, identified by micromorphological characterisation of their soil structure orientation (Illus 6 & 7), may have been a necessity to improve bonding within the narrow width of the cheek of 0.5m. In this way, at least two blocks could be placed side-by-side per course, and block length alternated between courses, in a rough header and stretcher pattern (Illus 6a & 7a; compare Illus 5).

To judge from experimental work as part of the Earthen Empire project, turf blocks of 0.58 × 0.33 × 0.10m, or 0.019m^3, would have weighed somewhere between 26 and 29kg, and perhaps as much as 35kg if they were particularly wet (Russell et al forthcoming). The advantages of using long blocks are evident – a coherent well-shaped turf block would be easier to use, speeding up construction. However, long blocks would have been more difficult to transport and prone to breaking in half when carried by one person. Scenes depicting fortification building on Trajan’s Column have been interpreted as showing Roman soldiers using different methods to carry turf blocks. Lepper & Frere (1988: 88) refer to Scene XXXIX as showing baskets being used to carry turf blocks. Hobley (1971: 23, 25) refers to the same scene, as well as Scenes XIX, XX, LX and LXV, as depicting soldiers using a rope harness to strap turf blocks to their backs (on this point, see also Breeze 2006: fig 6.15). More recently, Thill has cast doubt on previous interpretations of these scenes, questioning whether they show turf construction at all (Thill 2010: 31, 33). If the blocks shown on these Column of Trajan scenes are turf, they are considerably smaller than those identified at Laurieston. Large turf blocks could not have been carried in baskets (which would have been more useful for the loose earth employed in the layers at the base of the rampart). Instead, large blocks would have to have been carried individually, either cradled to the chest of the builder or in some form of harness or hod; alternatively, two people could have transported several long blocks on a stretcher or other carrier.

CONCLUSIONS: ‘ANOTHER WALL OF TURF’

The work at 72 Grahamsdyke Street, combining macroscopic field observations with micromorphological analysis, has shown that along this particular stretch of the Antonine Wall turf was used both in the cheeks and core of the rampart, even though the distinct black or red turf lines do not visibly survive. The implications of this are that turf may be present even when it is not apparent during excavation. Turf could therefore have been used more widely and more variably along the Wall than was previously appreciated. What had been linked to different work teams or later repairs, or the lack of suitable turf in the eastern sector (see Romankiewicz et al 2020a: 129, 137), may now simply be due to the different types of turf used, which varied in their subsoil composition and topsoil formation processes, and reflect different forms of landscape management and survival of vegetation cover. Indeed, this suggestion of more extensive use of different turf types is, to some extent, supported by the macroscopic evidence of other case studies reviewed above (Table 2).

More work is needed using micromorphology and other geoarchaeological methods to test how widely turf was used, but what our analysis suggests is that it is *possible* that Antoninus Pius’ Wall was indeed one of turf throughout – even in the part east of Watling Lodge. Our results show that where whitish material has been identified in section before, especially for the cheeks, and had been interpreted as clay or clay-rich earth, this could simply have been turf blocks, cut from a pale clay-rich top/subsoil with poorly developed or disturbed vegetation on top. Our earlier geotechnical assessment (Romankiewicz et al 2020a: 126–33, 136–8) had already highlighted possible structural complications and maintenance issues when using clay for the cheeks, especially if this material had also been compacted (compare Macdonald's 1934: 86 'wrought clay'). If many of these 'clay cheeks' were actually made of clay-rich turf blocks, with better moisture permeability than compacted clay due to their roots and vegetation content, this would have improved the geotechnical performance of the Wall and hence increased its long-term stability.

Our results also show that the lack of characteristic turf lines should not be taken per se as evidence for the absence of turf blocks; this absence needs to be tested in each case. The work presented here suggests that where these lines are missing, turf blocks could have been cut from areas where the grass horizons were already underdeveloped or eroded due to overgrazing or had been more heavily truncated. Where thick black lines of organic material remain, this may simply indicate thicker and less disturbed vegetation in the original cutting locations (compare the rusty-brown lines in the cheeks at Bantaskin or the greyish turfy line interpreted as the original ground surface below its upcast mound where 'once again no black stripe' survives; Keppie 1976: 72).

Ever since it was first noted that the construction of the eastern end of the Wall appears more heterogeneous than further west, it has been assumed that the materials used in the Wall varied in response to changes in topography, ground cover and land use along its line (Keppie 1976: 77–8; Davies 2020). Our new evidence, and our suggestion that turf may have been more widely used in the eastern sector, does not contradict these explanations; thinner, overgrazed turf in the east could simply indicate more intensive grazing regimes compared to less intensively grazed pastures in the west, retaining denser and perhaps rougher vegetation. The character of turf available to the builders of the Antonine Wall certainly differed considerably between Bridgeness and Old Kilpatrick, but differences in appearance of Wall sections do not necessarily mean a change in the overall construction method and materials. If turf were used all the way along, then the planning, sourcing and construction processes would have been synchronised along the length of the Wall too; only the type of turf would have varied, not the method of construction.

In Table 2, we have collected instances from east of Watling Lodge where either turf was already suspected or evidence remains ambiguous; this is a list of cases that would merit further investigations to clarify the field observations, if still accessible. This includes previously excavated evidence where earth mixes with only fragments of articulated turf are undoubtedly identified, which would deserve testing on their turf content overall. Many of these cases also survive below 0.20–0.40m in height and could thus represent the levelling layer on top of the stone base, rather than the original superstructure.

Beyond these points that require further, systematic analytical work, our first results already have far-reaching implications for our understanding of the monument. The careful construction and landscaping associated with the laying of the stone base confirm the importance of levelling; they represent a purposeful balance between sound construction, safeguarding against slumping, and considered, complex moisture management. There are further indicators of systematic planning and building, carried out with attention to detail: the addition of sand on top of the bedding layer; the selection of different types of turf for cheek and core; alternating between grass-up and grass-down orientation of blocks, and the laying of them in a diagonal arrangement, with core and cheek carefully keyed into each other. This all indicates the sophistication of turf building and engineering by the Roman army, which had been building turf ramparts in Britain for almost a century by the AD 140s. In many cases, the soldiers responsible for these structures would have brought turf-building traditions with them from their areas of recruitment and this knowledge was then retained within the units as part of their institutional memory (Russell et al

2021: 202–4). A unit's collective experience and knowledge would have developed to render them experts in understanding and using this material to its full advantage. The analysis outlined above also shows that the Antonine Wall was a carefully planned and executed building project – likely based on a systematic construction workflow – rather than a hastily drafted scheme. The progressive sequence of construction that links together the works for the base directly with the turf construction of the superstructure similarly demonstrates how operations were scheduled efficiently. This may have allowed for a speedy as well as careful construction (compare Hanson & Maxwell 1983: 79 on the efficiency of turf wall construction). The linking of these operations on base and superstructure does not contradict models that construction works could have been undertaken in parallel in different sectors (Keppie 1974; Hanson & Maxwell 1983: 117–18, 134–5; Hanson & Breeze 2020a: 21); however, the conclusion sheds little light on the question whether the Wall was executed to a pre-defined master plan with all fort locations already considered (Graafstal et al 2015; Graafstal 2020) or whether a change in plan resulted in primary and secondary fort locations (Hanson 2020; compare Hodgson 2020). What it does show is that the Antonine Wall was carefully constructed and seemingly built to last, for at least the 20–50 years that a turf structure can survive without major maintenance work (see Romankiewicz et al 2020a: 133–8). Slow erosion over time, followed by some more substantial deterioration deposits interspersed by working surfaces, indicate that the rampart stood soundly for a considerable time, but also that it would have needed regular maintenance. The small-scale erosion and trampling could already have occurred within a few years of construction; more substantial but not catastrophic erosion which was followed by repair and likely consolidation of upper levels was clearly happening at a later stage; but all this could have coincided within a single phase of Roman occupation (see Hodgson 1995; 2009; 2011; Hanson & Breeze 2020b). This might suggest that after *c* 25 years, when the turf rampart of the Antonine Wall would have needed substantial repairs, the decision was taken, in light of then-current political developments, to abandon rather than to rebuild (compare Hodgson 2009; 2011).

Further work is needed, building on these first promising results, to advance our understanding of the architecture and engineering aspects of the Antonine Wall and with it the broader question of its purpose and longevity. What our results have demonstrated is the need to routinely apply micromorphology when investigating earthen monuments like the Antonine Wall, the largest surviving turf structure from the Roman Empire.

Beyond the immediate Roman focus of this paper, its methods and results are also of wider relevance for studies of linear earthworks, which have seen renewed interest through the establishment of the *Offa's Dyke Journal* (Williams & Delaney 2019). The building technology angle of our study can offer an additional avenue of investigation for well-preserved earth and turf structures in northern Europe in particular, where a suite of geoarchaeological and geotechnical methods have already been successfully applied to multi-period field boundaries, settlement enclosures or burial mounds (eg Iceland: Einarsson 2002; 2015; Aldred et al 2007 and earlier reports; Wunderlich et al 2015; Denmark: Holst & Breuning-Madsen 2013; Nielsen & Dalsgaard 2017; Eriksen & Rindel 2018; general for geoarchaeological methods eg Kupiec & Milek 2015: 104–7). In-depth understanding of their methods of construction could cast further light on their important role in social, economic and political negotiations over access to land and management of resources through time (eg Holst 2013; Kupiec & Milek 2015). More broadly, our combination of micromorphology with macroscopic field recording of building processes informed by geotechnical analysis resonates with other interdisciplinary projects on linear earthen boundaries (eg Arnoldussen & van der Linden 2017; Arnoldussen 2018; Vervust et al 2020a; 2020b), adding a Roman period case study and its construction context to wider research portfolios into past agricultural environments and practices. We hope that our work has shown the potential that such a combined approach with micromorphology at its core can offer, to provide

TABLE 2
Construction details similar to 72 Grahamsdyke Street from excavated rampart sections east of Watling Lodge

Construction feature	*Site name*	*Evidence from macroscopic observation*	*Reference*	*Evidence from 72 Grahamsdyke Street / comment for further testing*
Bedding layer under stone base	Beancross	*'brown gravel and clay'* found in front of N face of rampart *'level with the bottom of the kerbstones'*, interpreted as subsoil	Bailey in Keppie et al 1995: 612–13	Compare with gravel layer C1014 under stone base, shown to contain clay-rich turf offcuts and concluded to have been a bedding layer.
Levelling layer of earth and turf offcuts above stone base	Beancross Trenches A and B	0.08m survives above stone base, *'grey clay-loam containing from one to three distinct bands of red-brown soil, interpreted as the turf block structure of the rampart'*	Bailey in Keppie et al 1995: 612	Three bands within 0.08m thickness at Beancross would suggest very thin turf blocks for superstructure – or compared with levelling layer C1004 0.10m thick, containing turf offcuts, the Beancross evidence could possibly represent turf offcut within a levelling layer.
	Callendar Park (1981)	*'Laid turf survived to a maximum of 0.2m above the base. Individual turves measured 0.15–0.2m long, and were 0.1m deep'*	Keppie & Walker 1989: 144	Low thickness of this layer surviving may be evidence of levelling layer, similar to C1004 – or compare survival within turf core C1001, with very few turf lines, yet still representing well-layered turf core.
	76 Grahamsdyke Street, Laurieston; structure to S of Wall	*'Between the turf layer and the natural was a … dark brown clay loam with charcoal flecks (layer 9) …* [representing a] *0.14m thick … cultivation soil upon which the turfwork was laid'*, containing traces of charcoal and calcined bone	Bailey 2021: 365, 367	Although this ancillary structure had no stone base, this layer may be evidence of the use of a levelling layer, similar to C1004, for a structure abutting the Antonine Wall rampart; possibly with similar levelling layer below the rampart.
	West annex defences Mumrills	Layer 14: *'compact blue-grey clay loam … Within its maximum depth of 0.08m there were two or three rust-coloured striations and patches of dark brown loam'*; *'clearly turf'*; one block 30cm × 25cm; layer directly on stone base	Bailey 2021: 313, illus 6.2	Section drawing suggests this to be a neat levelling layer of 0.08m thickness, similar to C1014 at 72 Grahamsdyke Street.
Turf cheeks	Meadows (Kinneil Park)	*'a good deal of whitish clay above* [south kerb]' 22 inches below then-present surface	Macdonald 1925: 276	Compare Keppie's statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.
	Kinneil Reservoir, 65 feet E of gate into Summerhouse Park	*'Clay was much in evidence, rising at one place in a solid mass for 7 inches'* (18cm)	Macdonald 1925: 275	Compare Keppie's statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.
	Stey Step road to Upper Kinneil	*'Clay … present in abundance'* in the area of the N kerb	Macdonald 1925: 274	Compare Keppie's statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.
	Inveravon	Mixed S cheek of *'blocks of clay and turf'* interleaved with clay and clay blocks	Dunwell & Ralston 1995: 526, illus 5.2 & 6	Mix of subsoils for turf cheeks, and keying into core.
	Polmont Hill, Field No. 825	*'traces of clay were observed among the soil towards the southern side'* of this rampart section, likely in area of S cheek; material surviving 18in (*c* 45cm) below the surface	Macdonald 1915: 137–8	Compare Keppie's statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.
	Little Kerse, western end of Field No. 833	*'among the freshly turned furrows a line of clay running parallel to the Ditch and apparently representing the north kerb'*	Macdonald 1915: 137	Compare Keppie's statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.

TABLE 2
Continued

Construction feature	*Site name*	*Evidence from macroscopic observation*	*Reference*	*Evidence from 72 Grahamsdyke Street / comment for further testing*
Turf cheeks *continued*	Polmont Churchyard, glebe field	*‘when this field was freshly ploughed, … two parallel lines of clay running east and west amid the ordinary soil’* – proven on excavation to be *‘piles of clay at the outer sides of the foundation … less massive than … at Mumrills’*	Macdonald 1915: 136	Compare Keppie’s statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.
	Polmont Park, E	One trench across S kerb revealed *‘distinct traces of a turf cheek’*, in others *‘no evidence for the use of clay’*; 0.85m wide cheeks	Steer 1961b: 322; compare Bailey 2021: 28	Compare Keppie’s statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.
	Polmont Park, W	Turf cheeks found ¾ mile E of Mumrills fort	Steer 1961a: 94 (ii) & 1961b: 322	Areas with turf and clay cheeks would merit further testing. Compare Bailey in Keppie et al 1995: 618.
	Polmont Park/ Cadger’s Brae	*‘faced on the north side by laid turf 2 feet 9 inches broad’* (*c* 85cm)	Steer 1961b: 323	Areas with turf and clay cheeks would merit further testing.
	Beancross	*‘pure yellow composition of the clay* [cheeks] *would seem to rule out the possibility of the cheeks having consisted originally of turf cut on a clayey subsoil’*	Bailey in Keppie et al 1995: 612; compare Macdonald 1915: 134	Evidence of cheeks at 72 Grahamsdyke Street, Laurieston, had similarly appeared as homogeneous whitish-grey clay.
	Mumrills E	*‘clay’* cheeks either side	Steer 1961a: 95 (iv)	Compare Keppie’s statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.
	20–30 yards W of Mumrills’ NW corner of fort	‘*yellow clay*’ cheeks 18in wide above N kerb, same as S kerb	Steer 1961a: 94–5 (iii), fig. 4	Compare Keppie’s statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.
	c 120m W of Mumrills’ NW corner	turf cheeks 18in deep, leached turfwork, whitish grey but clearly layered	Steer 1961a: 94 (i)	Areas with turf and clay cheeks would merit further testing.
	Lock 16	N kerb with *‘wrought clay’* spreading for some distance *‘outwards’*, no sign of lamination	Macdonald 1925: 284–5	Compare Keppie’s statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.
	Western annex defences Mumrills	*‘two lines or cheeks of pale cream clay loam’* consisting of two parts: outer (B) 0.45m deep *‘block of pale yellow/cream clay (slightly loamy)’*, steep face over front of kerbs (vertical?); inner (A) 0.45m deep into core, narrowing *‘towards the top’* with *‘thin bands of a similar loamy clay [as cheek B] but … interleaved with bands of pale grey loamy clay and brown loam’*	Bailey 2021: 312; compare 353	Compare Keppie’s statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil; evidence at the Western annex interpreted as earlier turf cheeks replaced by clay-rich material.
	Streets and houses of Laurieston	*‘clay … clinging to the stones, … no indication of the lamination characteristic of structures of turf’*	Macdonald 1915: 132	Compare Keppie’s statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.

Table 2
Continued

Construction feature	*Site name*	*Evidence from macroscopic observation*	*Reference*	*Evidence from 72 Grahamsdyke Street / comment for further testing*
Turf cheeks *continued*	Northby	*'accumulation of clay at the outer edges was well marked'*	Macdonald 1915: 133	Compare Keppie's statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.
	Callendar Park (1981, College of Education)	*'revetted by narrow turf cheeks, usually 0.3m wide, though occasionally somewhat broader'*	Keppie & Walker 1989: 144	Compare evidence for S cheek, in particular C1005.
	Falkirk, Kemper Avenue	*'revetted by turf cheeks c 1m wide', 'maximum height of 0.18m'*	Keppie & Murray 1981: 249	Compare evidence for S cheek, in particular C1005.
	Falkirk, Rosehall	*'Towards each of the edges, however, a certain amount of clay was visible'*	Macdonald 1915: 128	Compare Keppie's statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.
	Falkirk, Mayfield	clay cheeks	Macdonald 1925: 284	Compare Keppie's statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.
	Bantaskin	N cheek of *'greyish lumpy clay'*, interpreted by Keppie as *'turfwork'*, and another turf cheek on the south identified by *'horizontal rusty-brown lines'* of turf vegetation layers; also repair of N cheek in turf, no clay repair; distinction of soils between core and cheek confirmed by J Dickson, Glasgow	Keppie 1976: 71–2	Compare evidence for S cheek in particular C1005; compare Bailey 1995: 594: turf cheeks, difficult to identify because of *'very weak turf lines'*.
Turf core	Nether Kinneil	Turf superstructure	Price 1974: 68	Compare survival within turf core C1001, with very few turf lines, yet still representing well-layered turf core.
	Inveravon	*'core of light brown gritty earth containing a small number of discontinuous turf lines'*	Dunwell & Ralston 1995: 526, illus 5 & 6	Compare survival within turf core C1001, with very few turf lines, yet still representing well-layered turf core.
	Polmont Park	*'What little remained of the superstructure consisted of the natural sandy subsoil with the random addition of a few turves'*	Steer 1961b: 322	Low thickness of this layer surviving may be evidence of levelling layer (as per above), similar to C1004 – or compare survival within turf core C1001, with very few turf lines, yet still representing well-layered turf core.
	Polmont Park/ Cadger's Brae	*'10 inches … of a core* [surviving] *of dark brown sandy loam'* (25cm)	Steer 1961b: 323	Compare this 0.25m thick layer with survival within turf core C1001, with very few turf lines, yet still representing well-layered turf core.
	Beancross, Trenches A and B	0.08m survives above stone base, *'grey clay-loam containing from one to three distinct bands of red-brown soil, interpreted as the turf block structure of the rampart'*	Bailey in Keppie et al 1995: 612	0.08m thick layer above stone base with banded turf could also be remains of well-layered turf core – compare discussion above under 'levelling layer'.
	20–30 yards W of Mumrills' NW corner of fort	Core is *'brown sandy loam'*, surviving *'3 ft. 4 in.'* with yellow clay cheeks '*18 in. broad'* above N kerb, same as S kerb	Steer 1961a: 94–5 (iii) & fig 4	Compare survival within turf core C1001, with very few turf lines, yet still representing well-layered turf core.

TABLE 2
Continued

Construction feature	*Site name*	*Evidence from macroscopic observation*	*Reference*	*Evidence from 72 Grahamsdyke Street / comment for further testing*
Turf cheeks *continued*	*c* 120m W of Mumrills' NW corner of fort	no clay but 18in surviving of *'core': 'natural sandy subsoil, with occasional turves thrown in'*	Steer 1961a: 94 (i)	Thickness of this layer (0.45m) likely to be core and compare survival within turf core C1001, with very few turf lines, yet still representing well-layered turf core.
	Field 2095, W of Mumrills	*'above the stones'* not necessarily kerbs *'whitish mass'* [on one occasion] *'rose to a height of 3 feet 3 inches'*, no black lines, abundant clay	Macdonald 1925: 283	Compare survival within turf core C1001, with very few turf lines, yet still representing well-layered turf core; several other sections in Macdonald 1915 & 1925 describe lack of lamination in core, see sites under turf cheeks above.
	Lock 16	*'complete absence of lamination'*	Macdonald 1925: 284–5	Compare with survival within turf core C1001, with very few turf lines, yet still representing well-layered turf core.
	Callendar Park (1981, College of Education)	*'Laid turf survived to a maximum height of 0.2m above the base. Individual turves measured 0.15–0.2m long, and were 0.1m deep'*	Keppie & Walker 1989: 144	Compare survival within turf core C1001, with very few turf lines, yet still representing well-layered turf core.
	Callendar Park	*'photographs of the 1981 excavation in Callendar Park … too show … a turf core in one instance'*	Bailey 1995: 594	Compare survival within turf core C1001, with very few turf lines, yet still representing well-layered turf core.
	Bantaskin House	*'at least partly composed of clay, … nothing suggestive of sods'*	Macdonald 1925: 284	Compare Keppie's statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.
	Bantaskin	orange clayey core *'with some distinctive greyish … turf blocks thrown in'*	Keppie 1976: 71–2	Compare evidence for C1001 wall core.
Angled turf blocks	Callendar Park	Material marked 'E' in illus 3 is placed at a 45° angle *'decayed turf'*	Bailey 1995: illus 3	Compare Illus 6 above, Callendar Park plan, where these angled turf blocks are marked in pale red.
	West annex defences Mumrills	Layer 6 of possible turf wall structure against S of rampart: 45cm square blocks, *'grid pattern formed by these turfs lay at 45 degrees to the line of the Wall'*	Bailey 2021: 365, 367, illus 7.17	Compare Illus 6 above, showing 45° angled turf blocks in rampart core.
Keying of 'clay' cheeks into core	Inveravon	Mixed S cheek of *'blocks of clay and turf'* interleaved with clay	Dunwell & Ralston 1995: 526, illus 5.2 & 6	Mix of subsoils for turf cheeks, and keying into core.
	Beancross	Cheek material *'penetrating 0.3m into the centre of the rampart'*	Bailey in Keppie et al 1995: 612	Specific shape and form of this penetration unclear, may represent keying of cheek into core.
	Callendar Park	*'new cheeks* [B] *were wider, over 0.70m wide as compared with the previous 0.36m, presumably to increase stability'*	Bailey 1995: 587–8	Compare Illus 6 above, Callendar Park plan, where lighter grey cheeks at west trench interdigit with core.
	Western annex defences Mumrills	*'inner part, Cheek A, … interleaved with bands of pale grey loamy clay and brown loam …* [a]*t the base … extended a further 0.45m into the centre of the Wall'*	Bailey 2021: 312	Compare Keppie's statements in 1974: 161 and 1976: 77, about the possibility that this represents turf, cut on clayey soil.

more insight into what may have been a much more ubiquitous, but also much more sophisticated construction method, than is often assumed.

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