Turrets as watchtowers on Hadrian's Wall: a GIS and source-based analysis of appearance and surveillance capabilities

Alberto Bello Foglia

SUMMARY

This paper provides a GIS- and source-based assessment of the possible functions of the Turrets on Hadrian's Wall. Art, literature, and excavation reports were reviewed in an attempt to reconstruct their possible external appearance and to see what this might suggest about how Turrets could have been used. A GIS was constructed with the aim of testing a series of visibility-related questions about what could be seen from the top of a Turret, how far an observer could see, and conversely, if this reveals anything about the Turret's height. The essay then investigates how the results of this research impacts upon the use of Turrets as signalling-platforms.

INTRODUCTION

Preamble

> '... owing to the extreme severity and inevitableness of the punishment, the night watches of the Roman army are most scrupulously kept' (Polybius 1927, 6.35).

For the Romans, as for any other military and security force throughout history, surveillance was one of the most important aspects of maintaining security — be this of a military camp, a city, or a frontier. The importance of surveillance to the Romans is evident by the fact that death was the punishment for falling asleep or failing to be on post during one's watch (Brand 1968, 57–8). Vegetius also extols the value of watching: 'In war, he who spends more time watching in outposts and puts more effort into training soldiers, will be less subject to danger' (Vegetius 1993, 3.26). Without anyone keeping watch, even the tallest barrier could be crossed with impunity, and the largest armies could be surrounded and destroyed in ambushes.

One key element in keeping watch over the Wall must have been the Turrets. With some exceptions, such as the additional tower at Peel Gap, it is now known that two Turrets were constructed between each Milecastle, spaced roughly 500 m apart. Whilst Turrets are the focus of this paper, there were other towers incorporated into the Wall. For example where the Wall crossed rivers, the bridges constructed to carry it over were flanked by towers. It is also assumed Milecastles had towers of their own, though this is still debated (Symonds 2013, 55). Scholars have often recognised that this network of structures formed an observation system (e.g. Bruce 2006, 72; Breeze and Dobson 1972, 186; Charlesworth 1977, 23; and Dobson 1986, 9). Towers had often been used as watch-posts in antiquity; raised platforms were very beneficial in lifting the sentry above surrounding obstacles, and thus increasing the area that could be kept under watch. Yet, in the past the spacing of Turrets and Milecastles was

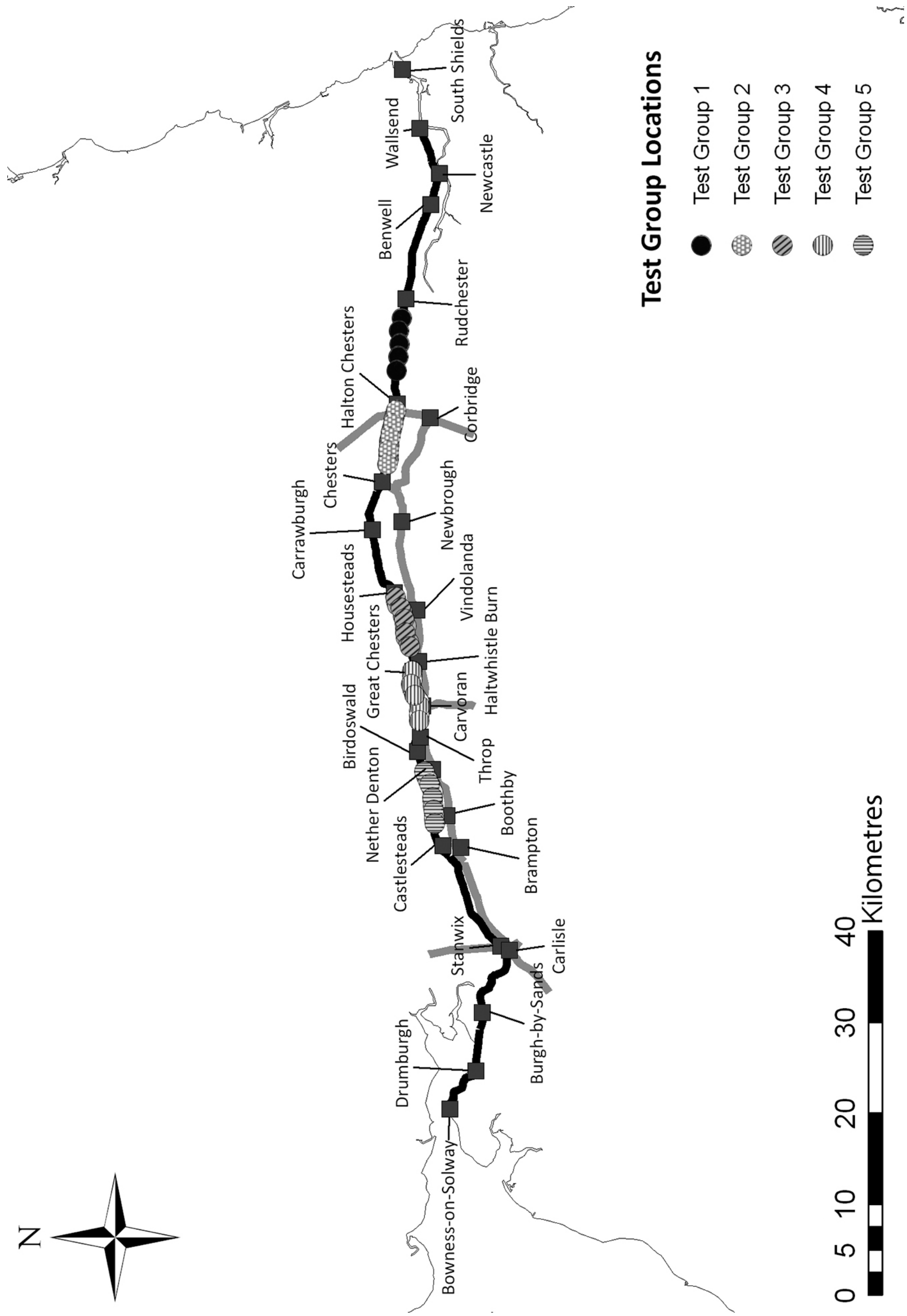

Fig. 1 Relative position of the Test Groups. (Author).

criticised as being too rigid to properly function as watchtowers; to keep to the intended spacing some Turrets were placed in locations with poor views to the north (Charlesworth 1977, 23). Towards the end of the second century, most of the Turrets were demolished, an action which strongly suggests that they may not have been serving their intended function. Recent research shows the spacing was actually quite flexible: some Turrets were placed out of their 'measured' position in order to take better advantage of the terrain (Symonds 2013, 58–9), or to improve signalling (Woolliscroft 2001, 59–66).

Summary of argument

How Hadrian's Wall functioned as an observation system has not been studied in much depth so far, but an appreciation of this is an important step towards gaining a better understanding of the overall function of the frontier. Turrets were probably a key component of this system. The aim of this study was to review and analyse the literature and evidence regarding Turrets, and to use this information to build a GIS to help answer questions about the appearance of these towers and the surveillance capabilities of the Wall network. It was also hoped that the GIS could help to answer other questions about the Turrets, such as why they were demolished, and what other possible functions they may have served. The results seem to point towards Turrets providing only local surveillance for the line of the Wall, and not that they were used for spotting distant incoming threats. Their eventual demolition in the central sector appears to be simply due to redundancy.

Terminology and measurements

In quoting older records, Imperial measurements have been converted into metric. For the measurements of Roman structures, the nearest equivalent in Roman feet is provided. The Roman foot is calculated as being equivalent to 29.6 cm (Giuliani 2010, 283). In this paper, the abbreviation 'rf' after a measurement will be used for Roman feet. For example, the measurement for a wall height might be given as 5 m ($16\frac{11}{12}$ rf). The Roman mile, the *miliarum* of 5,000 rf (1.48 km), which is also the average distance between Milecastles, is abbreviated to 'rm'.

METHODOLOGY

GIS — DESIGN AND VIEWSHEDS

Design and viewshed introduction

The project specification was to create a GIS in ArcGIS 9.3 that could test visibility-related questions along Hadrian's Wall. Even though this paper focuses on Turrets as part of the surveillance system, Milecastles, forts, and other installations such as gates through the Wall, and towers guarding the bridges had to be added to the GIS to provide an uninterrupted observation network. Both Milecastles and forts also had towers of their own, and the Turrets would have worked alongside them to create an even field of coverage. There were various questions which needed answering to assess how the Wall's observation network functioned, and how successful its design proved to be. What was the quality and coverage of the observation network? How did the addition of forts, and the later removal of some Turrets, influence the observation network? Did the design of the Wall take into account the capability

Table 1 The Test Groups

Test Group number	Installations in Group
Test Group 1	All Turrets and Milecastles between and including MC15–19
Test Group 2	All Turrets and Milecastles between and including MC22–26
Test Group 3	All Turrets and Milecastles between and including MC37–40
Test Group 4	All Turrets and Milecastles between and including the Fort at Great Chesters and MC47
Test Group 5	All Turrets and Milecastles between and including MC51–55

of human eyesight to resolve objects at different distances, and did this influence its design? Would it be possible to pinpoint an optimal height for Turrets by testing different published estimates?

The first step was to plot the whole Wall to test issues with overall coverage in its layout before and after the addition of the forts. Subsequently, five test-groups were then chosen to test local visibility issues. The aim was to choose stretches of the Wall that were well recorded, to minimise errors resulting from incorrectly guessing at Turret and Milecastle locations. Areas with interesting features, such as Pike Hill and Peel Gap — where an additional tower was provided — were also given priority. These groups are listed in Table 1. Their relative locations along the Wall are shown in fig. 1. Additional groups for testing specific aspects were created on a case-by-case basis. These are explained in detail in their relevant section in this paper. The main analytical tool used for all groups was the viewshed.

Viewsheds are raster-maps that display the area visible from one or more locations (Wheatley and Gillings 2002, 204). Rasters are a type of data structure used in GIS where the graphical information is displayed as various small parts, usually termed cells (Wheatley and Gillings 2002, 50). A raster divides the study area into a grid, each cell in the grid representing a smaller area of space. Each cell is then assigned a value. A very familiar form of a raster in action is a digital image. In digital images, the cells are termed pixels, and each pixel has a value assigned to it that represents a colour or shade. For GIS purposes, the value could be a height, a density or even a visibility index. The latter is the case for viewsheds.

There are two different basic types of viewsheds. The standard viewshed is binary, with each cell listed only as visible or not visible from a single observer location. A standard viewshed generated from multiple observer locations is known as a multiple viewshed. There is also the cumulative viewshed. This can only be done when the viewshed for multiple viewpoints is calculated. Instead of listing whether a cell is or is not visible, a cumulative viewshed lists how many observer points can view each cell (Wheatley and Gillings 2002, 206–9). Only the multiple viewshed was used in this case. Before any viewshed can be created, two different inputs are needed: observer points from which to calculate the viewshed, and elevation information for the landscape. These will be explained in the GIS construction section.

'Higuchi' viewsheds

One of the issues with normal viewsheds is that they do not give information about how visibility drops off over distance (Wheatley and Gillings 2002, 214). When considering surveillance capabilities of a system, this is quite important. It does not matter how far someone can see, if an object cannot be resolved at that distance. This aspect is rarely considered when commenting on visibility from ancient watchtowers. Wheatley and Gillings (2000, 13–16) discuss a way to solve this by creating what they call a 'Higuchi' viewshed. Higuchi, influenced by his background as a Japanese landscape planner, suggested that trees provided a reliable way to measure clarity over distance. Wheatley and Gillings used this approach to create a solution to the shortcomings of viewsheds (2000, 13–14). In the Higuchi method, the visibility is divided into short, middle, and long-distance bands. At short distances, trees and their details are clearly visible as separate objects. Middle distance is where the outlines of treetops are visible, and long distance is where an area can be recognised as wooded, but nothing more (Wheatley and Gillings 2000, 14–15).

The steps required to generate a Higuchi viewshed are simple. First, a raster with the distance bands from the observer points has to be created. After that, the viewshed in binary form has to be applied on top of it as a 'cookie-cutter' mask (Wheatley and Gillings 2000, 15–16). The obvious problem with a standard 'Higuchi' viewshed is that it looks at the visibility of trees while a sentry on a watchtower would be looking for human activity. This meant that different criteria were needed when selecting distance bands for this analysis.

One possibility was to calculate at what distance humans could be distinguished by the naked eye. Russ (2007, 89) explains the way to calculate this is to multiply the size of the observed object by 3,000 to get the maximum distance that it can be viewed from, expressed in metres. This is a slightly problematic way of doing things though, since based on this equation a human-shaped object, 1.8 m tall, should technically be recognizable at 5.4 km. Yet, an object of about 22 cm — the size of the author's head — will only be distinguishable at 660 m. This means that distinguishing a human sized object, and actually being able to recognise it as a human are two different things. Background contrast is also important — if an object is a similar colour or pattern to its background it will blend in, making it more difficult to distinguish at further distances. Russ unfortunately does not provide a method of compensating for this factor, even though the problem is recognised.

Goldsworthy (1996, 152) has an interesting section in his book dealing with the Roman army, where he discusses what a Roman general would be able to see on the battlefield. To give us some indication, he provides us with some figures taken from a Victorian artillery manual (Table 2). At that time, the best way to gauge ranges for artillery on the battlefield was

Table 2 Recognition distances on a battlefield. Taken from Goldsworthy (1996, 152)

Distance	What can be seen
1550 m	Masses of troops recognised.
1300 m	Infantry distinguishable from cavalry.
900 m	Individuals can be seen.
640 m	Heads, cross-belts, etc. can be recognised.
450 m	Uniforms recognised, weapon reflections can be seen.
225 m	Officers recognisable, uniforms clear.

by using soldiers as a form of measuring stick. Designed for battlefield use, the estimates also take into account the clarity of distinguishing soldiers from their background — in this case, masses of similarly uniformed troops. This provided a good basis for the visibility bands in a 'Higuchi' style viewshed for this model. Moreover, a quick check shows how close these figures are to those attained by using Russ's calculations for distance of resolution: 640 m is listed in the manual as the distance at which heads become distinguishable. Following the formula provided in Russ (2007, 89), this results in a head size of 21.33 cm. It must be stressed that these figures are only for a person with ideal eyesight, and so the actual resolution distances varied from soldier to soldier.

Considering the fact that at distances greater than 1550 m masses of troops cannot be recognised, it was decided to create a buffer limit for all the viewsheds at an arbitrary 2222 m. This meant that only terrain within that distance would be considered when calculating the viewshed; this resulted in a significantly reduced calculation time.

GIS — CONSTRUCTION

Elevation information for Britain is provided by Ordnance Survey (OS) and, subject to certain conditions, can be downloaded free of charge from EDINA's digimap service (Edina n.d.). Various formats are provided for download, and the raster DEM versions were selected. DEM stands for Digital Elevation Model, and a raster DEM assigns each cell an elevation value above Ordnance Datum. Two levels of resolution are provided as options. The OS Land-Form PANORAMA map series is at 1:50,000 scale, meaning that each cell represents an area of 50 by 50 m; the OS Land-Form PROFILE is at 1:10,000 scale and so each cell represents an area of 10 by 10 m. The latter was selected for its higher resolution, allowing for the finest detail over the entire area calculated. All of the OS data were divided up into squares measuring 10 by 10 km within the OS grid. The next step, defining the observation points for the viewsheds, was more difficult.

Finding exact data on the coordinates of all the Turrets, Milecastles, and forts was rather difficult. Whilst all items had OS coordinates listed in PastScape (English Heritage n.d.), having to search manually for each individual structure in the database was deemed too time-consuming a task, a decision made also in part due to the lack of confidence in the accuracy of the coordinates given. On PastScape many of the coordinates are very vague, sometimes only providing the OS Grid square and not anything more precise. The task was rendered even more difficult because not all of the structures along the Wall have been found or excavated, so the position of many Turrets and Milecastles is unknown. It was decided that the best course was a two-fold approach. First, the latest OS map for each 1:10,000 grid square was downloaded, and laid over the corresponding DEM. OS maps list the positions of all known historical monuments, including the line of Hadrian's Wall and the structures along it. All that was necessary at this stage was to place an observer point over each marked structure. The line of the Wall was also drawn in. The known sites and stretches of Wall were then cross-referenced with both the *Handbook to the Roman Wall* (Bruce 2006), which provides location data for each known structure, and the 2010 edition of the English Heritage *Archaeological Map of Hadrian's Wall*. Each site for which the location was not known was placed in its 'measured' location, taking this from the known locations of adjacent Milecastle and Turrets. The attribute information for each observer point was edited to include details as to whether the site's position was known or hypothetical.

GIS — METHODOLOGICAL ISSUES

It is important to note the various methodological issues inherent in GIS viewsheds, and how these affected this particular study. These issues are sufficiently significant for it to have been suggested that at best a viewshed should only be considered a 'probability surface' — meaning that results can only imply the likelihood of a cell being seen (Wheatley and Gillings 2002, 209). The reasons for this are multiple, and range from the quality and accuracy of the data, to problems simulating issues that might affect visibility. An example is the above-mentioned issues with fall-off in clarity over distance.

Data issues in this study are two-fold: the accuracy of the DEM used, and the accuracy of the coordinates used for the observer points. Since each cell in the DEM represents an area of 100 sq m, it means that when gathering the data, only a single point was taken every ten metres, and so any smaller variations in elevation were missed. Depending on the height of the observer, even a small variation can have a large effect on the area viewed — and so even if the DEM is accurate overall, a small set of errors can throw the results out (Wheatley and Gillings 2002, 209). There are also issues with the accuracy of the equipment used to take the elevation information, which may allow errors of even up to a few metres to creep into the dataset. Perhaps more importantly, in this study, is the lack of accurate coordinates for the large number of the Turrets that have not been excavated. This means that on the less explored eastern and western sectors Turrets that have been placed in their 'measured' position might be in places that the Romans may have avoided building on. This can heavily affect the data. For this reason, in the smaller test group areas, only Wall sections with known Turrets were chosen.

Another major problem lies with the more practical issues of simulating real-world aspects of visibility. Two that have already been discussed are how visibility falls off over distance, and issues with the clarity of an object against its background. Other issues revolve around recreating the landscape as it was during the time of the Romans. Vegetation, such as large forests, could have a large effect on what visibility was like during that period. Whilst a lot of good work has been done on the environment during the time of the Wall (Symonds and Mason 2009a, 108–18), it is impossible to repopulate the landscape with its original tree cover. Other issues include how environmental conditions might affect visibility (such as fog, rain, or the hours of darkness), and simulating how viewsheds can alter based on the movement of either the observer or the target. A full list of all the issues and critiques of visibility analyses in a GIS are provided in Wheatley and Gillings (2002, 216).

There are also issues with how viewsheds are calculated. Multiple and cumulative viewsheds only keep track of whether a cell is visible or not, or how many observers can see it — not *which* observers can see it. While this was not a problem when testing view coverage, it was for the overall accuracy of the 'Higuchi' viewsheds. An example of this issue is illustrated in fig. 2. Let us assume a 'Higuchi' multiple viewshed is generated with Turrets A and B as observer points. The dotted circle is the maximum radius at which an object can be seen in this 'Higuchi' viewshed. For the soldier to be considered visible within the GIS, he has to fulfil two criteria: he has to be within the view radius of an observer point, and within the line of sight of an observer point. The problem is the GIS does not differentiate between which radius the target is in, and from which point a line of sight can be drawn to the target. In this example, the soldier would be considered visible as he is within the radius of Turret B, and in the line of sight of a sentry on Turret A. This defeats the purpose of the 'Higuchi' viewshed

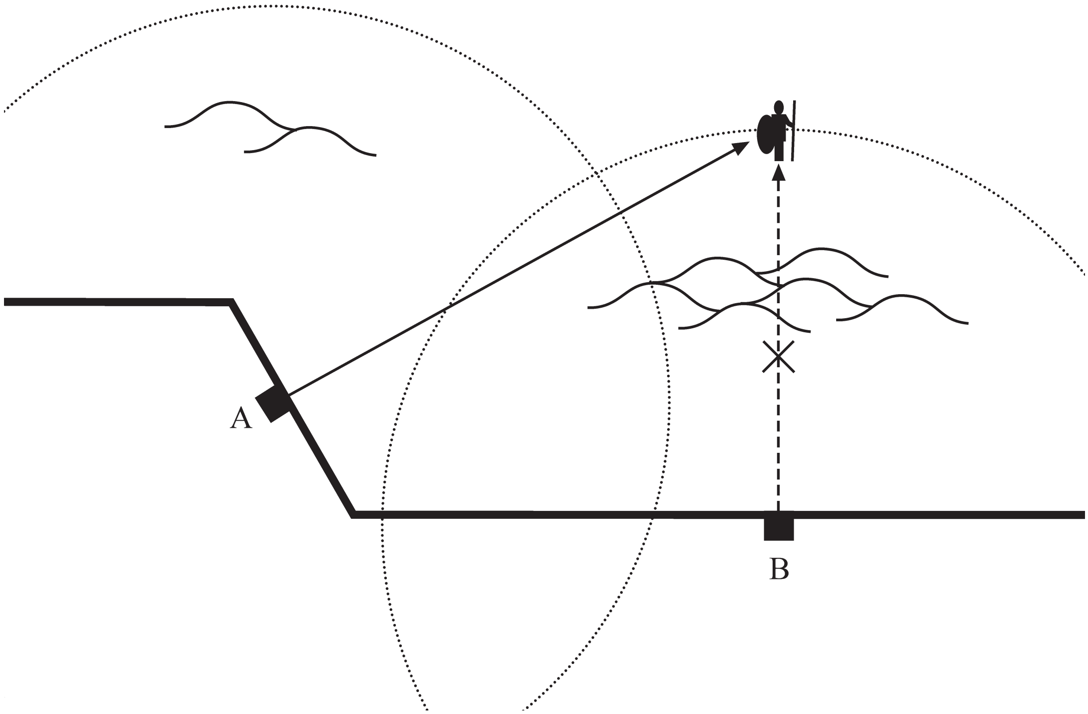

Fig. 2 Schematic representation of the differentiation issue. (Author).

in this case. To be truly visible the soldier would have to be within the line of sight Turret B because he is in the view radius of Turret B. The only way to overcome this fault is to create a separate viewshed for each Turret — a very time-consuming task, especially since it is unlikely that this issue would heavily influence the results.

Finally, it is important to mention that the results of a viewshed show association and not causation (Wheatley and Gillings 2002, 209). Possible patterns in visibility from the Turrets may be entirely down to coincidence. To prove that this was not the case, it is still important to assess the archaeological and literary data. Even though there are some issues with using viewsheds, this does not mean they are not useful. Whilst they cannot be relied upon for exact precision, they still give a good indication of a general pattern or situation.

DISCUSSION

THE STRUCTURE AND APPEARANCE OF TURRETS

When considering the role of Turrets as watchtowers there are two important aspects of their external appearance that must be considered. The first is where the sentry would stand watch. Did they have to stand in a roofed room with only windows to peer out of, or on a balcony, or on an open roof? The second is how high the Turrets were. The goal of a watchtower is to provide an elevated platform that raises the sentry above obstacles and allows them to see more and further.

Unfortunately, evidence for how Turrets were roofed is scarce. In terms of archaeological traces, only a single fragment of ceramic roof tile has been found at T18b (Charlesworth 1977, 14–15), and a few stone slates pierced with nail-holes in T29b and T44b (Crow 1991, 61; Hill and Dobson 1992, 42–3; Bruce 2006, 71). It is possible they had a flat roof with a crenellated parapet; in Turrets 7b and SW T51b, stones that were assumed to be complete merlon capstones have turned up (Birley 1930, 150; Crow 1991, 61; Hill and Dobson 1992, 33).

There are problems with flat roofs. At 61 cm across, the conjectured merlons may be too narrow, and consequently the embrasures too large (Hill and Dobson 1992, 33). Yet, there is good archaeological evidence for wide embrasures, at least during the first century. At the Praetorian Camp in Rome, up until the time of Vespasian at least, small merlons were set 12 rf (3.5 m) apart (Richmond 1927, 14). The city walls of Roman Fondi had embrasures of 2.4 m (8 rf) and at Pompeii they were 1.5 m (5 rf) (Hobley 1989, 31). Vegetius also mentions centurions measuring rampart work with 10 rf (2.96 m) rods (Vegetius 1993, 3.8). This may have been the case at Lunt, as 10 rf was the spacing of timber piles supporting the forts' battlements and to which the merlons may have been attached — again, leaving wide embrasures (Hobley 1989, 31). Since flat roofs would need to be made of timber, Hill and Dobson (1992, 40–3) argue against them; a leak in the wet northern climate would lead to rotten timbers. They also point to the lack of archaeological evidence for watertight materials, such as lead or pitch. There is evidence from Greece for setting stones in clay for waterproofing wall-walks (Lawrence 1979, 356) and Vitruvius advocated the mixing of olive-oil into mortar to make it waterproof, at least when making a waterproof layer for a multilayer flat roof (Vitruvius 1999, 7.1.7). So even a lack of finds of more traditional waterproofing materials does not prove that flat roofs could not be made waterproof. Hill (1997) uses this Vitruvian style roof in his reconstruction of a flat roofed tower.

The alternative was a pitched roof, either pyramidal in shape or with gable ends. Many scholars believe this was the case (Hill and Dobson 1992, 42; Charlesworth 1977, 14; Brewis 1932, 200–1). A pitched roof would shed rainwater, and thus better protect the structure and the occupants of a Turret from the northern climate. There is a paucity of tile and slate finds though, which would be the strongest evidence for pitched roofs. Some scholars therefore suggest that perhaps they were covered with perishable materials such as thatch or wood shingles (Hill and Dobson 1992, 42–3; Bruce 2006, 71).

Roman art depicts towers with both types of roof. Trajan's column has two types of tower: watchtowers with pyramidal roofs and a balcony (fig.3.b), and a tower in the same scene with a gable roof (fig.3.a, fig.3.c) (Lepper and Frere 1988, 48; Settis *et al*. 1988, 259–61). The latter type of tower also appears in four other scenes: XXXI (Lepper and Frere 1988, 79), XXXIV–XXXV (Lepper and Frere 1988, 84), XLV (Lepper and Frere 1988, 90) and LXXXIX (Lepper and Frere 1988, 138). Late Roman coins and medallions show towers with conical roofs (Johnson 1983, 40–3), as does a scene on the Ribchester helmet (Robinson 1975, 111). The Rudge Cup and Amiens Patera, which list names of some of the western Wall Forts, may depict crenelated towers on the Wall (fig.3.d). Crenelated fortifications were a common ancient motif though, so these might not be a true-to-life depiction (Bidwell *et al*. 1989, 157; Crow 1989, 149).

The presence of balconies on some of the towers depicted on Trajan's column lead some to suggest the possibility of balconies on Turrets (Dobson 1986, 9). Evidence for such balconies

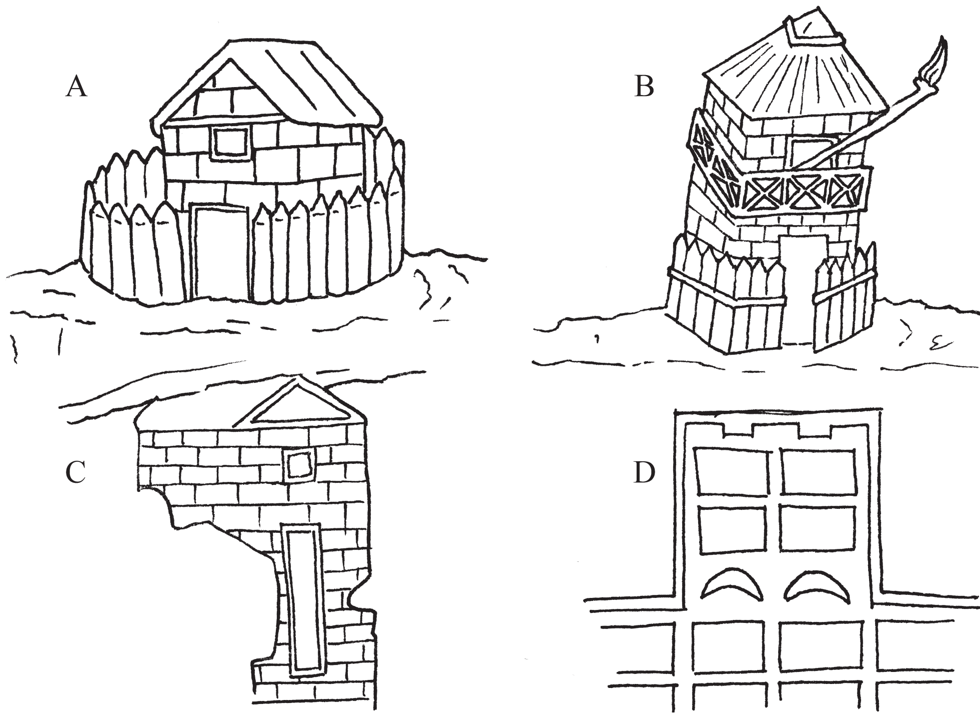

Fig. 3 Towers in Roman Art: a–c from Trajan's Column, d from the Rudge Cup. (Author).

does exist in some earlier ancient Greek towers. A few have sockets for cantilevered beams (Lawrence 1979, 219). At Aiya Marina there is a tower with intact marble corbels, probably for supporting an exterior gallery or balcony (Lawrence 1979, 195–6). Allason-Jones (1988, 219), however, refutes this claim for Turrets. She points to a lack of finds of large iron nails that would be needed to hold such a structure together.

Considering that Turrets have noticeable differences in the layout of their ground plan, depending on who built them, it may have also been that the different legionary gangs may have favoured different types of roof. Turrets may well have been re-roofed at a later point in their life cycle, a point made by Bellhouse (1969, 83). Each Turret should ideally be regarded as a separate structure when using evidence to reconstruct elevations.

Judging how the structure of the Turret may affect its visibility is a very difficult task. A balcony, or a flat roof, especially one with narrow merlons and wide embrasures, would probably provide a better view than an enclosed room with windows, depending on the quantity and size of the windows.

The most significant factor for observation is likely to have been the height of the Turret. Unfortunately, there is no archaeological evidence for their height. All heights presented in reconstructions are entirely hypothetical, and taller towers are not necessarily better. Hill and Dobson (1992, 41) pointed out that in terms of pure horizon distance after a certain point the positives of increased height start to drop off. So there was probably a happy medium for tower height — an ideal height, offering maximum visibility over the terrain and maximum

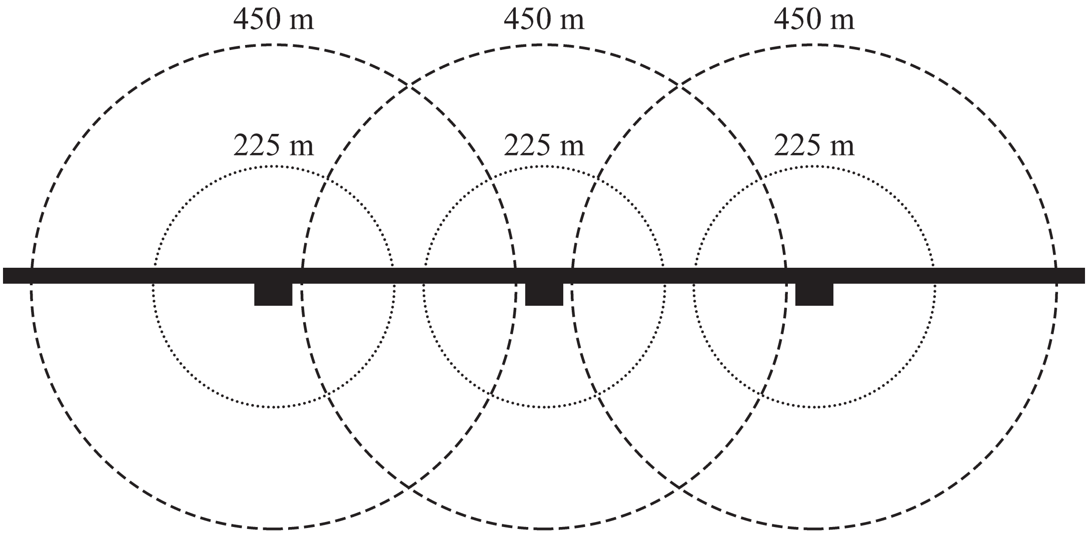

Fig. 4 Schematic representation of Turret spacing and view radii. (Author).

stability. The height might be varied depending upon the terrain: in some situations, a taller tower might be needed to be able to see over higher obstacles. This is why height is one of the variables tested using the GIS. By testing different heights, it may be possible to get a better estimate for the original height of the Turrets.

Possible towers above Milecastles must also be considered, since Milecastles would have been an integral part of the Wall's observation network, although, as was previously mentioned, there is some doubt about Milecastle towers (Symonds 2013, 55). If they did exist, it is likely that these towers would have been similar to Turrets in appearance. There is negative evidence that at least one of them had a flat roof, as the remains of a collapse in MC27 produced no sign of roof tiles (Crow 1989, 151).

SPACING, VIEW DISTANCE, AND VISIBILITY GAPS

In its original conception, Hadrian's Wall only had Turrets and Milecastles incorporated into the Wall itself. These were spaced at a regular interval of roughly 500 m, although there are instances of both shorter and longer intervals. A cursory look at Table 2 gives a possible reason why an interval of 500 m was chosen — it is very close to the 450 m that is the maximum distance where military uniforms, and therefore friend/foe or civilian/militant, can be recognised. Half that distance, 225 m, is the minimum range at which uniforms are clear. Therefore, intervals of 500 m would allow sentries to clearly distinguish exactly who was approaching along the whole length of the Wall without needing to leave their posts (fig. 4). If this choice of spacing were indeed a result of human vision, then we would also expect to see a similar spacing of analogous structures on other frontiers. In fact, this appears to be the case on Rome's other major land frontier, the German *limes*. Here the towers and fortlets are also spaced at an average of 500 m (Breeze 2012, 87). The regular spacing therefore is not necessarily a sign that the Wall was designed by someone disconnected from the realities of the terrain, as is sometimes implied (Charlesworth 1977, 23). It may be that the regularity was a product of the limitations of human eyesight.

Another aspect that stands out is how short the useful view is. Individuals, according to the view bands, only become distinguishable from a similar background at around 900 m. Without modern aides, such as binoculars, it seems quite probable therefore that the towers were only for observing activity in the areas *immediately surrounding* the Wall, and not for spotting distant incoming threats. There was evidence for this in the viewsheds for all the Test Groups (below), which in many cases, whilst having limited views to the north, could still offer a clear view along the length of the Wall. In most modern border security fences, this is what the imaging sensors and watchtowers are for — to spot *local* intrusion attempts in time to react and deter them. This is the case for the Israel and Palestine West Bank Fence, where the Israeli Defence Force monitoring equipment is so advanced they can react to intrusions in six minutes (Donaldson 2005, 180) — and the United States-Mexico border fences (Andreas 2000, 92). It is probable therefore that the Wall Turrets functioned more as 'security cameras' than long-distance 'radar'. Roman 'radar' may have taken the form of advance scouts, such as the *exploratores* units created during the later empire for the specific purpose of gathering intelligence (Goldsworthy 1996, 125–6).

At this point it is worth noting how difficult it was, up until recently, to spot even large groups of incoming enemies at any distance. As Goldsworthy (1996, 125) points out, 'in the ancient world, when armies were small and compact in comparison to the large areas of country a campaign might cover, the simple need to find the enemy was paramount'. It seems highly doubtful then that even a Turret with an exceptionally good view would enable a sentry to spot an enemy army before the latter was almost up to the Wall. Criticism that the rigidity of the spacing resulted in poor outlooks for some Turrets, such as in Charlesworth (1977, 14) or in Bruce (2006) may be misdirected. The spacing was probably to mainly provide 'high resolution' short-range cover, rather than the long-range early-warning system which seems to be the underlying belief. This would have been provided by the scouting parties.

Another aspect that stood out was the presence of gaps in the coverage of the Wall. Test Group 3 was a particularly good example as it had a very large gap in visibility. This gap was reduced by the later addition of an extra Turret, known as the Peel Gap Tower (Frere *et al*. 1987, 316–7). Test Group 3 was tested both with and without the Peel Gap Tower, and the results showed quite clearly that the Tower filled in the hole in view coverage created by Peel Gap (fig. 5). The view north is quite poor, and from the Peel Gap Tower no sentry could have seen out of the little valley that is the Gap. This led Crow (1991, 53) to believe that its location was solely due to spacing reasons, as T39a and T39b are abnormally far apart. Yet, the blind-spot created by the Gap is over 100 m wide and 200 m long. This would have allowed a very easy approach to the Wall. It seems significantly more probable that the Tower was specifically placed there as an extra 'security camera' to plug a hole in a system of local observation. Symonds (2013, 59) also recognizes this and makes the same argument.

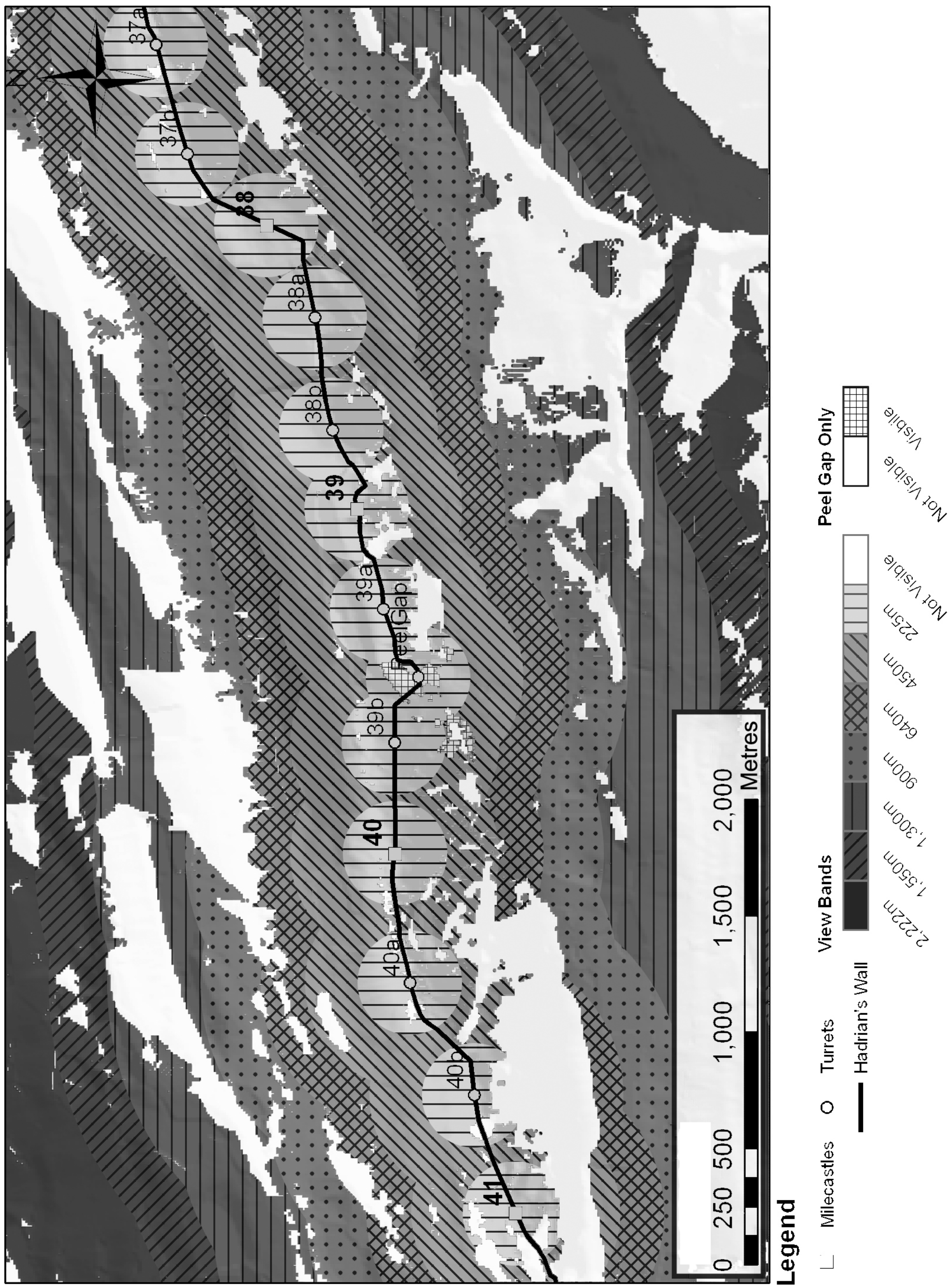

Fig. 5 Section of Test Group 3 'Higuchi' viewshed. Hatched area shows gap in viewshed filled in by the Peel Gap Tower. (Author).

Peel Gap is not the only blind-spot. In Test Group 3 alone, there are smaller gaps between MC39 and T39a, T38b and MC39, and between T40b and MC41 — some of these perhaps due to DEM inaccuracies. Most of them are not as severe as that at Peel Gap, as they occur over cliff faces. Gaps seem to be restricted to the rough terrain of the Whin Sill. None is visible anywhere else in the full Wall length viewsheds that were generated.

VISIBLE SURFACE AREA IN RELATION TO HEIGHT

If the idea that Turrets and Milecastle towers performed the function of short-range surveillance platforms were accepted, then the importance of the height of the tower would not lie in the ability to see farther into the distance, but in raising the observer higher than surrounding obstacles. Since the viewshed raster counts how many cells are registered as visible, it was therefore possible to calculate and then compare the areas visible from different heights. This was done for all five Test Groups. Other tests included the Wall layout before and after the addition of the forts, and consideration of the Turrets that are known to have been demolished. The hope was to spot trends that could indicate what Turret height may have been preferable, or why certain Turrets were destroyed, and to determine whether there was a tendency to prefer increasing views of the north over south, or *vice versa*.

Each test involved generating four viewsheds from different observer levels. These were based on Hill's (1997) Turret reconstruction, as it went into the most detail. The first observer level was at ground level, in order to have a base with which to compare the other heights. The second level was a hypothetical wall-walk (cf. Bidwell 2008) at 4.44 m (15 rf). The last two were from a roofed tower with its highest floor at 7.4 m (25 rf), and a flat roofed tower at 10.36 m (35 rf). All levels had an additional 1.5 m added to them, to simulate eye-level.

Raising the observer from ground level to Wall height provided an overall area increase of between 13.5%, in Test Group 4, and 58% in Test Group 2, with the rest falling between 20 and 30%. Raising the observer level from the hypothetical wall-walk to the lower of the two tower heights, at 7.4 m, only provided an extra overall increase of more than 10% on one occasion — though raising from the wall level to 10.36 m provided regular increases of 10% or more.

Looking at the full length of the Wall, the results are similar. Before the decision to add the forts, lifting an observer from ground level to the hypothetical wall-walk provided an overall increase of 25.3%. From there to the first tower height of 8.9 m (7.4 + 1.5 m) was only a 6.6% increase, but from Wall level to the second tower height of 11.86 m (10.36 + 1.5 m) it was 12.1%. Nothing really changed after the forts were added, with results staying at 24.3%, 6.9% and 12.2% respectively. More curious are the results for the Turrets that are known to have been demolished and had their recess filled in, at 37%, 10% and 19.8% respectively. This is in line with view area increases seen elsewhere, so that seems to exclude the possibility of them being razed for providing sub-standard outlooks.

These results are difficult to judge. It is hard to know what the Romans would have considered a useful increase. It does seem that the flat-roofed tower with an observer level of 11.86 m may have been preferable. In nearly all cases, it provided an extra increase of at least 10% over an observer on the curtain wall. Of course, these results are based on the supposition that there was actually a wall-walk from which observation was possible. If not, the increase in viewing area by either tower height from ground level was very significant. It may even be that Turrets and other towers were of different heights on different stretches of the wall, depending on how good or bad the views were from ground level at that location.

TEST GROUPS — NORTH *VS* SOUTH, AND TURRET DEMOLITION

An overall visible area was calculated for each Test Group, as well as a north and a south visible area. Out of the five Test Groups, three of them provided a greater area of view to the north than to the south at all observer levels. Test Group 1 was interesting in that an observer at ground level could see more to the south than to the north. Yet, from the top of the curtain wall, an observer could see marginally more to the north, and from the top of either Turret height, significantly more to the north.

Test Group 2 had the lowest amount of visible surface area out of all the Test Groups, especially from ground level. Hills blocked the views both to the north and to the south, but the views to the north were noticeably better. Here, all observer heights provided massive increases in visible area. At curtain-wall level, the visible area increased by 58%. The highest tower height provided a 111% increase in visible area over ground level. Visible area was increased by roughly the same amount both to the north and the south as the height increased. Higher Turrets appear to have been very helpful in this sector.

Test Group 3 was in the central sector on the Whin Sill crags. Whilst more surface area was visible to the north, increasing the height of the observer improved the views to the south more. From the height of the curtain wall the visible surface area increased by 13.2% to the north and 54.7% to the south. The lowest Turret height increased the visible area from ground level by 17.2% and 72.4% respectively — the highest, by 20% and 82.5%. This may support the signalling system proposed by Woolliscroft for this area (Woolliscroft 2001, 67–73). By improving views to the south, it would be easier to contact the forts along the Stanegate. Notably in this group, every Turret except for one is known to have been demolished. It could be hypothesized that the Turrets were removed as they did not significantly improve the views to the north, and that over the crags there was less chance that the Wall could be crossed. The question would then be how more vulnerable points of the Wall in this area, such as at Peel Gap, could be kept under surveillance. This may point to the existence of a wall-walk, and there is a platform abutting the Peel Gap Tower that could be interpreted as stairs (Bruce 2006, 260). It also brings in to question Woolliscroft's signalling hypothesis, at least in the later phases of the Wall's operational life.

Test Group 4 crosses terrain more open than that of Test Group 3. More surface area was visible to the north rather than the south here as well. Like Test Group 3, an increase in the height of the observer did not significantly increase the visible area to the north. Unlike Test Group 3, the increases to the south were even worse. Here no Turrets are known to have been demolished. This may be because this was a more open landscape, where keeping closer watch was more important.

Test Group 5 is the only Group where the view south remained better than the view to the north, even as the height of the observer was raised. The viewable area to the north increased more than to the south in this case. Test Group 5 is also curious for having an extra tower at Pike Hill very near to T52a, for a reason not discernible from the viewsheds. Whilst T52a was demolished, Pike Hill seems to have been occupied until the fourth century (Bruce 2006, 321). It may be that the presence of the Pike Hill tower made T52a redundant, although this was not tested. Further to the west, T54a was also demolished (Bruce 2006, 327). Again, the viewsheds do not indicate any possible reason why. This Turret had previously collapsed and had to be rebuilt further south; it could be that soil in the area was unstable, and that structural problems in the new Turret meant that it was not worth keeping.

EFFECTS OF STRUCTURAL CHANGES

Throughout its lifetime the Wall was subject to various changes in plan. This section will look at how those changes may have affected visibility from the Wall, and if that can tell us any more about the reasons behind them. The first major change was the early decision to add a series of forts to the line of the Wall, often on top of pre-existing Turrets or Milecastles. The second was the late second-century decision to demolish at least some, if not all, of the Turrets (Charlesworth 1977, 21–2).

In terms of visible area, the addition of the forts did not change anything. For the purposes of the GIS, each fort was given only one observer-point, drawn over their north gate, though they could have also had sentries on each of their corner and interval towers. All the addition of the forts did was to increase the visible area from the higher tower height by an insignificant 0.3% overall.

The effect of the demolition of the Turrets is more interesting. How would the garrisons in the Milecastles perform without the Turrets? Whilst it is believed that only the Turrets in the central sector were demolished, all Test Groups had a viewshed generated from just the Milecastles to assess their performance nonetheless. What became immediately clear was that in terms of surface area covered, the visibility from the Milecastles alone is satisfactory. In Test Groups 1, 2 and 5, the Turrets only provided an increase in visibility of 20% or less over just the Milecastles. In Test Group 4, it was just 9%. Only in Test Group 3 did the Turrets provide a significant increase in visible area: 34.5%. This is interesting, since this is the main sector where the Turrets were demolished. This again may point to an existence of a wall-walk along the top of the Wall. In terms of the resolution of the coverage, the average halfway point between Milecastles, at 740 m, is still well within the 900 m maximum for distinguishing individuals, and close to the 640 m needed to recognise heads. This is similar spacing to the Roman towers on the Gask Ridge in Scotland (Donaldson 1988, 352–3).

The few Turrets that seem to have been maintained until the fourth century, such as 44b (Crow 1991, 61) and perhaps up to six others (Charlesworth 1977, 21–2) were probably kept for specific reasons. Perhaps the fort that garrisoned them still had a use for them, or they covered an area of particular importance.

TURRETS AS SIGNALLING TOWERS

Very few structures are built with only a single purpose in mind, and so it is quite likely that Turrets had other functions aside from watching the Wall. A very commonly cited and well-explored function is their possible use as signalling towers. How did the outer appearance of Turrets and surveillance capabilities affect this?

Woolliscroft's *Roman Military Signalling* is the culmination of his research into the signalling capabilities of Roman frontier systems. He goes into detail on the possible methods used for communication and has some excellent research on sight-lines between Turrets, forts and Milecastles. He also makes the important point that messages were mostly delivered by messengers, and that signalling was only to transmit emergency messages quickly over long distances (Woolliscroft 2001, 13). He prefers beacons to other signalling methods, due to their simplicity (Wooliscroft 2001, 64). Some evidence in support of Woolliscroft's hypothesis has already been presented, but there are still two conflicts between Woolliscroft (2001) and the current study. One has already been mentioned, that the removal of Turrets in the late second

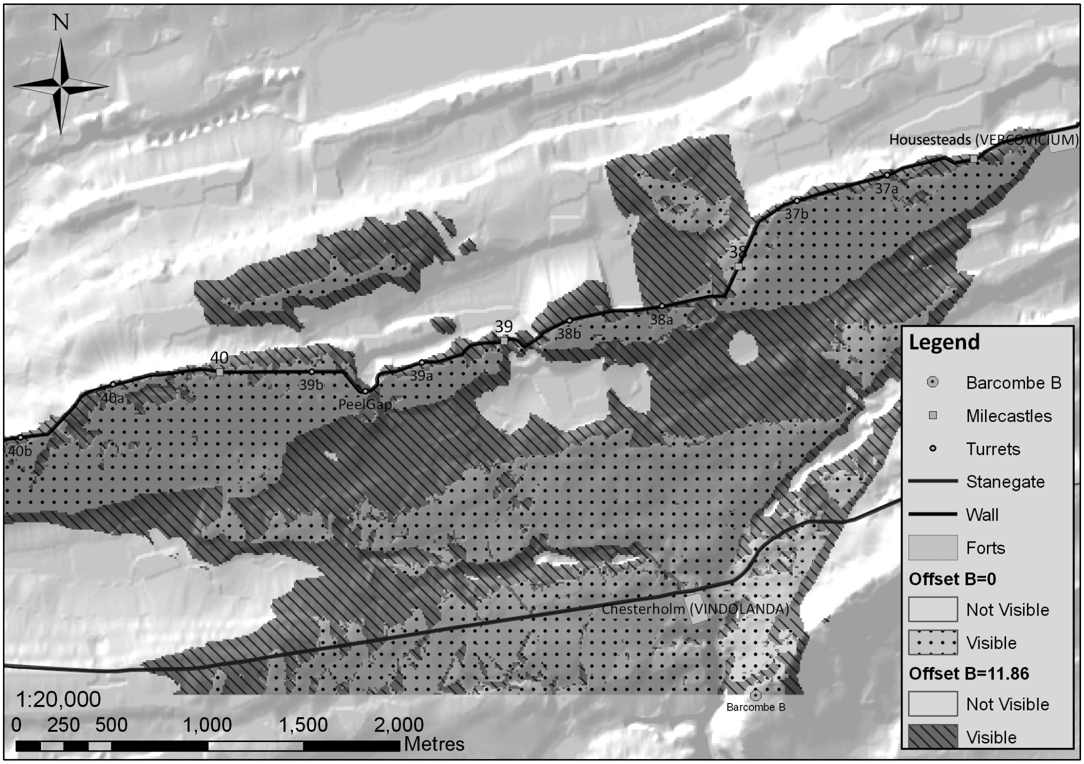

Fig. 6 Viewsheds generated from hypothetical 'Barcombe B' tower to test Woolliscroft signalling hypothesis. Offset B = 0 is for signal targets at ground level, Offset B = 11.86 is additional visible areas for signal targets at a high turret level. (Author).

century might have compromised the signalling system. The second lies in the nature of the appearance of the Turrets. He seems to prefer placing signalling systems on top of the Turrets (Woolliscroft 2001, 36–46). It is an obvious problem — if Turrets were roofed, where would the beacon be placed? Lighting a large fire in a closed room with a wooden ceiling is not an option! This is also pointed out by Southern (1990, 238). This is either another point in favour of flat, crenelated roofs or a problem with Woolliscroft's hypothesis. Would his signalling system still work if the beacons were placed at ground level, or from a hanging fire basket? A GIS viewshed test of the area of the hypothetical signalling system centred around Signal Tower B on Barcombe Hill, suggests that Wooliscroft's system would still be feasible (fig. 6).

CONCLUSION

Turrets were an integral part of the surveillance system of the frontier, creating a tight network for observing activity along the line of the Wall. Their rigid spacing was probably designed to maximise the 'resolution' of the observation screen, allowing the sentries to be able to tell with more confidence who was approaching the Wall, and to monitor their activities. The decisions as to whether the Turrets had flat or pitched roofs, and even their height, might have been up to the original builders. These things were not standardised — any more than the door locations of the Turrets were standardised. The decision on the height of each Turret might have been dictated by the visibility across the immediate terrain. It seems unlikely that any Turret had an exterior balcony, although having a balcony or a flat roof would probably have been an advantage, as they would provide clearer views than just a room with windows. These uncertainties, and the lack of standardisation, demands that each Turret should be reconstructed on the specific evidence found within it.

It was found that in four of the five Test Groups, more was visible to the north than to the south by an observer raised above ground level. In the only Group that had worse views to the south, raising the observer above ground level primarily increased the viewable area to the north. This may suggest that observing activity to the north of the Wall was indeed a priority. The addition of forts to the Wall seems to have changed little in terms of the surface area visible from the observation screen.

The demolition of Turrets in the central sector seems to have been tied to its unique terrain — that formed a formidable barrier on its own — and to the fact that having Turrets did not improve the observable area to the north by much. The reason for the demolition of Turrets in other sectors of the Wall is less clear. None of the other proposed functions of the Turrets are affected by the tentative arguments of this paper, and they may also have served as signalling posts that were able to defend themselves.

There is a lot more to be investigated about Turrets, particularly about their manning. Egyptian *ostraca* that give information on outpost duties and watch cycles of the Roman army (Clarysse and Sijpesteijn 1988; Gallazzi 1989; Bülow-Jacobsen 1997; Cuvigny 1997) could be used to try and reconstruct a possible service rota and to estimate garrisons for Turrets. This would have affected their surveillance capabilities.

This study shows that despite potential flaws in the data that affect the reliability of the results, interesting conclusions can still be reached using computer models. Whilst it could never fully replace field exploration, GIS serves as an excellent platform for testing visibility-related questions in archaeology.

BIBLIOGRAPHY

ALLASON-JONES, L. 1988 'Small finds from Turrets on Hadrian's Wall', *in* Coulston, J. C. *Military Equipment and the Identity of Roman Soldiers*, Oxford, 197–233.

ANDREAS, P. 2000 *Border Games: Policing the U.S.-Mexico Divide*, Cornell.

BECKER, T. 2008 'Nature and function of reconstructions on the Upper German-Raetian Limes using the example of wooden watch-towers', *in* Breeze, D. J. and Jilek, S. *Frontiers of the Roman Empire: The European Dimension of a World Heritage Site*, Edinburgh, 153–62.

BELLHOUSE, R. L. 1969 'Roman sites on the Cumberland Coast 1966–1967', CW^2 69, 54–101.

BIDWELL, P., MIKET, R. and FORD, B. 1989 'The reconstruction of a gate at the Roman fort of South Shields', *in* Bidwell, P., Miket, R. and Ford, B. (eds.) *Portae cum turribus*, Oxford, 155–231.

BIDWELL, P. 2008 'Did Hadrian's Wall have a wall-walk?', *in* Bidwell, P. (ed.) *Understanding Hadrian's Wall*, Newcastle, 129–43.

BIRLEY, E. 1930 'Excavations on Hadrian's Wall west of Newcastle upon Tyne in 1929', AA^4, 7, 145–52.

BRAND, C. E. 1968 *Roman Military Law*, Austin.

BREEZE, D. J. 2012 *The Frontiers of Imperial Rome*, Barnsley.

BREEZE, D. J. 2003 'Warfare in Britain and the building of Hadrian's Wall', AA^5, 32, 13–6.

BREEZE, D. J. and DOBSON, B. 1972 'Hadrian's Wall: some problems', *Britannia*, 4, 182–208.

BREWIS, P. 1932 'Conjectural Construction of Turret No. 18a on Hadrian's Wall.' AA^4, 9, 198–204.

BRUCE J. C. 2006 *Handbook to the Roman Wall*, 14th ed., [ed.] Breeze, D. J., Newcastle upon Tyne.

BÜLOW-JACOBSEN, A. 1997 'Lists of Vigiles (309–356)', *in* Bingen, J., Bülow-Jacobsen, A., Cockle, W. E. H., Cuvigny, H., Kayser, F. and van Rengen, W. (eds.). *Mons Claudianus. Ostraca Graeca et Latina II*. France: Institut Français D'Archéologie Orientale.

CHARLESWORTH, D. 1977 'The Turrets on Hadrian's Wall', *in* Apted, M. R, Gilyard-Beer R. and Saunders, A. D. (eds.) *Ancient Monuments and their Interpretation*, London.

CLARYSSE, W. and SIJPESTEIJN, P. J. 1988 'A Military roster on a vase in Amsterdam', *Ancient Society*, 19, 71–96.

CROW, J. 1989 'Notes on the north gateway of Milecastle 39, Castle Nick', *in* Bidwell, P., Miket, R. and Ford, B. (eds.) *Portae cum turribus*. Oxford, 143–4.

CROW, J. 1991 'A review of current research on the Turrets and curtain of Hadrian's Wall'. *Britannia*, 22, 51–63.

CUVIGNY, H. 1997 'Tableaux de Service (304–308).', *in* Bingen, J., Bülow-Jacobsen, A., Cockle, W. E. H., Cuvigny, H., Kayser, F. and van Rengen, W. (eds.). *Mons Claudianus. Ostraca Graeca et Latina II*, Institut Français D'Archéologie Orientale.

DOBSON, B. 1986 'The function of Hadrian's Wall', *AA*[5], 14, 1–30.

DONALDSON, G. H. 1988 'Signalling communications and the Roman imperial army', *Britannia*, 19, 349–56.

DONALDSON, J. W. 2005 'Fencing the line: analysis of the recent rise in security measures along disputed and undisputed boundaries', *in* Zureik, E. and Salter, M. B. (eds.) *Global Surveillance and Policing: Borders, Security, Identity*. Devon, 173–93.

EDINA n.d. *Digimap Collection*. Available at: http://edina.ac.uk/digimap/ (July 5, 2011).

ENGLISH HERITAGE n.d. *PastScape*. Available at: http://www.pastscape.org.uk/ (August 7, 2011).

FRERE, S. S., HASSALL, M. W. C., and TOMLIN, R. S. O. 1987 'Roman Britain in 1986', *Britannia*, 18, 301–77.

GALLAZZI, C. 1989 'Un nuovo frammento del vaso di Amsterdam *O.Amst*.8'. *Ancient Society*, 20, 185–90.

GIULIANI, C. F. 2010 L'edilizia nell'antichità, Rome.

GOLDSWORTHY, A. K. 1996 *The Roman Army at War 100BC–200AD*, Oxford.

HILL, P. R. and DOBSON, B. 1992 'The design of Hadrian's Wall and its implications', *AA*[5], 20, 27–50.

HILL, P. R. 1997 'The Stone Wall Turrets of Hadrian's Wall', *AA*[5], 25, 27–49.

HODGSON, N. 2009 *Hadrian's Wall 1999–2009: A Summary of Excavation and Research*, Kendal and Newcastle.

HOBLEY, B. 1989 'The evidence for the form and appearance of turf and timber defences of Roman forts in the late first century, based on experiments at the Lunt Roman fort', *in* Bidwell, P., Miket, R. and Ford, B. (eds.) *Portae cum turribus*, Oxford, 25–61.

JOHNSON, S. 1983 *Late Roman Fortifications*, London.

LAWRENCE, A. W. 1979 *Greek Aims in Fortification*, Oxford.

LEPPER, F. and FRERE, S. S. 1988 *Trajan's Column*, Gloucester.

POLYBIUS 1927 *The Histories*. 6 volumes. Trans. Paton, W. R., London.

RICHMOND, I. A. 1927 'The relation of the Praetorian Camp to Aurelian's Wall of Rome', *Papers of the British School at Rome*, 10, 12–22.

ROBINSON, H. R. 1975 *The Armour of Imperial Rome*, London.

RUSS, J. C. 2007 *The Image Processing Handbook (5th ed.)*, Boca Raton.

SETTIS, S. LA REGINA, A. AGOSTI, G. and FARINELLA, V. 1988 *La Colonna Traiana*, Turin.

SOUTHERN, P. 1990 'Signalling versus illumination on Roman frontiers', *Britannia*, 21, 233–42.

SYMONDS, M. F. A. 2013 'Gateways or garrisons? Designing, building, and manning the Milecastles', *in* Collins, R. and Symonds M. F. A. (eds.), *Breaking Down Boundaries: Hadrian's Wall in the 21st Century*, Journal of Roman Archaeology Supplement, Portsmouth, Rhode Island, 53–70.

SYMONDS, M. F. A. and MASON D. J. P. (eds.) 2009a *Frontiers of Knowledge: A Research Framework for Hadrian's Wall, Vol. I: Resource Assessment*. Available: http://www.dur.ac.uk/archaeology/research/projects/?mode=project&id=485

SYMONDS, M. F. A. and MASON D. J. P. (eds.) 2009b *Frontiers of Knowledge: A Research Framework for Hadrian's Wall, Vol. 2: Agenda and Strategy*. Available: http://www.dur.ac.uk/archaeology/research/projects/?mode=project&id=485

VEGETIUS 1993 *Epitome of Military Science*. Trans. Milner, N. P., Liverpool.

VITRUVIUS 1999 *Ten Books on Architecture*. Trans. Rowland, I. D., Cambridge.

WHEATLEY, D. and GILLINGS, M. 2000 'Vision, Perception and GIS: some notes on the development of enriched approaches to the study of archaeological visibility', *in* Lock, G. R. (ed.) *Beyond the Map: Archaeology and Spatial Technologies*, Amsterdam.

WHEATLEY, D. and GILLINGS, M. 2002 *Spatial Technology and Archaeology: The Archaeological Applications of GIS*, London.

WOOLLISCROFT, D. J. 2001 *Roman Military Signalling*, Stroud.

WOOLLISCROFT, D. J, SWAN, S. A. M. and LOCKETT, N. J. 1992 'Barcombe B, a second Roman "signal" tower on Barcombe Hill', *AA5*, 20, 57–62.

4250 Jewell Street, Apt. 110, San Diego CA 92109, USA.

abinhof@gmail.com