To See and to be Seen – the Antonine Wall in the Context of Spatial Analysis

Michal Dyčka

ABSTRACT
How did frontiers actually work? This essential question has been discussed over the last centuries through and through and the presented paper tries to offer a new perspective – this time by means of a landscape study and gaining an understanding of the positioning of individual forts on one of the short-lived Roman frontiers, the Antonine Wall. In the spotlight of this study is the spatial positioning of individual forts and fortlets on the above-mentioned frontier in terms of what could have been seen from them (visibility to the landscape and intervisibility with other Roman military installations) and how unique their locations were in terms of general accessibility (could they serve as natural blocking points?). A new approach is presented by using the Viewshed and Cost path analyses of the digital elevation model of the broader area around the Antonine Wall.

KEYWORDS
Antonine Wall; Viewshed analysis; Cost path analysis.

INTRODUCTION

Whenever we study the theme of Roman frontiers, we should always try to answer the fundamental question: how did Roman frontiers actually work? This paper offers some new ideas about this subject, primarily on the basis of evidence collected by the use of the spatial analyses performed in the programs ArcGIS 10.3 and QGIS 1.8.0 Lisboa of one particular part of the Roman frontier system, the Antonine Wall.

Two major issues are discussed in this paper: the visibility and intervisibility on the limes and questions concerning the accessibility of individual sites on the Antonine Wall. The first set of queries tries to find an answer to questions such as were Roman sites on the Antonine Wall intervisible or what kind of landscape observation the spots chosen for Roman forts and fortlets offered. The second group is more concerned with movement. Could some forts serve as natural blocking points in the landscape? Which direction did the roads connecting individual Roman sites on the limes take? These are just some questions that can be answered via study in an artificial environment.

STUDY AREA

The study area is not limited only to the Wall but includes the broader Antonine frontier system in Scotland (for detailed summary see Hanson – Maxwell 1983). For the needs of this study, the Antonine military installations in Scotland were divided into several groups (see Appendix). Apart from the Wall itself (which is not a part of the study and was in terms of visibility recently examined by Poulter (2009, 89–131), the core of the frontier system consisted of the so called primary forts constructed together or shortly before the Wall itself in around

142 AD. Not much later (the exact timing is a matter of debate) the so-called secondary forts were constructed on the line of the Antonine Wall and they are considered in this paper as the second group of fortifications despite such differentiation being recently questioned by Graafstaal *et al.* (2015, 54–70). The third subgroup consists of smaller installations on the line of the Wall, the fortlets. Originally, they should each have been separated by one Roman mile (1.48 km) from the other along the line of the Antonine Wall (Breeze 2008, 85–86). However, only nine of them are known for certain and therefore only those are included in this study.

Apart from the military installations positioned directly on the line of the Antonine Wall, the whole frontier system also consisted of the bases that followed the coastline. Two subgroups can be identified here, the forts positioned in the proximity of the estuaries of the rivers Forth and Clyde and fortlets situated even farther away off the Antonine Wall on the western coast. The last subgroup taken into consideration in this study is a group of four fortifications north of the Antonine Wall.

Due to the limited scope of this paper, some Roman forts, primarily those, whose existence and exact whereabouts are only expected or presumed (forts at Bridgeness, Kinglass, Kinneil and Polmonthill) are ignored here. However, those military installations which cannot be nowadays firmly and unequivocally dated as Antonine (e.g. Garnhall: Woolliscroft 2008, 129–176; Poulter 2009, 117–129) but could fit into either the system of signal communication or effective frontier observation are not omitted completely here. Another group of Roman sites not mentioned in this study is a broad set of Antonine military sites, which were not in the direct proximity of the frontier area but were positioned farther to the south and east like Bothwellhaugh, Inveresk, etc.

TECHNICAL SPECIFICATION OF THE PERFORMED ANALYSES AND USED TERRAIN MODELS

The input data for all conclusions presented in this paper are:

OS Terrain 50 Contours – 10 m contours. Version: 07/2014 – supplied under the licence of the Ordnance Survey – Great Britain's national mapping agency (http://www.ordnancesurvey.co.uk/business-and-government/licensing/using-creating-data-with-os-products/os-opendata.html)

OS Terrain 50 Contours – Spot heights. Version: 07/2014 – supplied under the licence of the Ordnance Survey – Great Britain's national mapping agency (http://www.ordnancesurvey.co.uk/business-and-government/licensing/using-creating-data-with-os-products/os--opendata.html)

GIS database data for forts and other Roman military installations along the Antonine Wall – Supplied under the licence of the Royal Commission on the Ancient and Historical Monuments of Scotland – RCAHMS Enterprises Content Licence, Content Order IMSL-IR-54739.

Through all the work, the British National Grid is used as a default coordinate system and all the listed x/y coordinates use this system. In order to perform the Viewshed analysis the author of this paper initially had to create a Raster DEM (a grid of squares or height map representing elevation in the Digital Elevation Model). The first step was to create a TIN DEM (Digital Elevation Model based on a grid of irregular triangles: Chapman 2006, 73) from OS Terrain 50 Contours – 10 m contours and OS Terrain 50 Contours – Spot heights via Create TIN tool in ArcGIS 10. 3. In order to make the TIN surface more realistic the author used the Constrained Delaunay triangulation instead of Delaunay triangulation and left all other settings on default. TIN DEM was then converted into Raster DEM with an individual cell size of 5 m square and all other settings on default. An alternative approach of creating DEM directly

from input data via the Topo to Raster interpolation tool offered a slight height deviation in comparison to the previously mentioned model and thus a different terrain shape especially in the flatter areas, but the results of the Viewshed analysis in terms of visibility and intervisibility were generally very similar.

In the created Raster DEM, several points were chosen to compare their Z values (altitudes) with real world altitudes. The deviation of the model from reality was in the example of Bar Hill (x:270746 y:675926) less than 2 m. This fort lies at 149 m.a.s.l. (Robertson 1975, 1), the Z value for the cell in the middle of the fort in the created Raster DEM is 151 m.a.s.l., the positions of the individual four gates were clockwise from the northern one 146, 148, 146 and 146 m.a.s.l. The altitude deviation in other examples never exceeded 5 m, although with higher elevation (approximately 500 m.a.s.l. and more) it rose. Also with higher altitudes, the peaks of the mountains (for example the peak of Beinn Dorain, x:232552 y:737853) were frequently not only 2–5 m lower than in reality but also moved to the south west by almost 8 m (to x:232550 y:737860). However, in the study area, the Forth-Clyde isthmus, the horizontal and vertical deviations from reality are generally minimal, often less than 1 m.

It is of course questionable how much the landscape of the Iron Age resembled the present-day landscape. The presented Raster DEM is not a copy of the existing actual landscape, not only because of the mentioned deviations, but also because there are no trees and other vegetation included in that model and the microtopography of land features smaller than 10 m square is simply omitted. Wharfs and other products of modern infrastructure are included in the model, but they make just a little difference to the results of the Viewshed analysis. The author did not try to reconstruct the landscape of past times but simply based his model on the belief that the general trend and shape of the landscape was more or less the same 2000 years ago as it is now.

The conclusions of this paper are based on the assumption that although climatic and vegetation conditions were probably a bit different than now (Peaty 1998, 203–214), hills and valleys were located where they are now. Probably the biggest change in the study area happened with the building of the Forth Clyde Canal at the end of the 18th century. This mainly affected the area around the western part of the Antonine Wall which generally became less wet and therefore more accessible but the altitudes of the terrain probably did not change dramatically. The coastline, especially in the area of the estuaries of the Forth and Clyde, also changed during the last 2000 years, mainly because of the silting up of rivers and shifts of sea level. Summarizing the above-mentioned there may have been some changes in the landscape since the Roman occupation of the present-day Scotland up to now, especially in the coastline regions, but due to the lack of knowledge of how exactly the landscape of Scotland in the Iron Age looked like, the author simply presumed that it was more or less the same as now. In this regard, the DEM is imperfect.

Having the 3D model (DEM) of the landscape, the author could perform the Viewshed analysis (Chapman 2006, 83–85; Conolly – Lake 2006, 225–233; Howard 2007, 281–282). The exact positioning of individual sites was included in the RCAHMS shapefile mentioned above to which the author added the surface information in ArcGIS 10.3 based on the elevation value of cells belonging to their x/y coordinates of individual forts and fortlets in Raster DEM. The Viewshed itself was, for more realistic results calculated not from a single central point as a view from the centre of a fort in the perigon (360° visual field), but from the spots of the four gates at once in the case of individual forts (whenever that was possible – exceptions are the Carriden, Inveravon, Falkirk, Kirkintilloch and Bishopton forts due to the limited knowledge of the position of all the gates in these cases). The fortlets Viewshed was due to their small size calculated just from the central point.

The Viewshed analysis was always calculated from the height of 5 m above the surface (OFFSETA in attribute table) which compensated for the minimal height of the forts/fortlets wall (more than 3 m: Breeze 2008, 75) and the height of the average man (less than 2 m). It is quite probable that the towers above the gates in forts like Mumrills or Castlecary were in fact higher (Maxwell 1989, 178–181) but in order to keep things relatively simple only the minimal value was applied. The only exception was the already mentioned Garnhall where a 9 m OFFSETA was applied because of an explicit statement of the excavator that this structure was a tower (Woolliscroft 2008, 163). In general, the results could only have been better and any kind of exaggeration was evaded as much as possible. It is of course imperative to remember that the capacities of not only a model, but also of Viewshed analysis are limited (Wheatley – Gilllings 2000, 1–27).

The Viewshed of all the sites mentioned in the Appendix (except Garnhall) was separately calculated with a 5 m OFFSETA and then once again with a 5 m OFFSETA + 5 m OFFSETB. The 5 m OFFSETB means that the line of sight was calculated not only from the height of 5 m above the ground (including the altitude of the line of sight of the observer – transmitter) but also with the top of a hypothetical 5 m tall platform (including altitude of the line of sight of the observer – receiver) which would be seen even in spots where the base of that hypothetical tower would remain invisible due to blocking by terrain (see also Conolly – Lake 2006, 229–230). In theory, that means that two platforms could have been intervisible even if potential observers could not see the ground on which the other tower was standing but could see the top of the opposite platform. Therefore, in theory that means that data proving intervisibility in this model counts with threshold values. Nevertheless, those results appear very often (see Appendix) so they can be either coincidental (improbable) or intentional (to maintain intervisibility even on the threshold) or simply the platforms/towers were higher than the mentioned minimal 5 m. All Viewsheds were calculated on default mode except the mentioned OFFSETA and OFFSETB and with an applied earth curvature correction at a value of 0.13 (Conolly – Lake 2006, 228–229).

For calculating the Cost path analysis (Chapman 2006, 107–111), a different model was used. In order to achieve hydrologically correct terrain, a linear interpolation via Topo to Raster tool was used with an output cell size of 5 m. From this model, a cost surface via Slope tool was made with default preferences. All other calculations of a Least cost path analysis were calculated on default using this cost surface.

WHY EVEN DO SPATIAL ANALYSES ANYWAY?

Since the Viewshed analysis and its interpretation are the main content of this paper (a cost path was performed only in two cases), it is good to start with their justification. The first eligible question to ask here is: Why even do a Viewshed analysis (in the above-mentioned artificial environment) to answer such a simple question as the visibility from chosen spots? It can be easily answered through observation on site!

The first reason is that work with Viewshed analysis in DEM offers a researcher a much broader perspective. One is able to identify some features that are common for a multitude of sites and are otherwise unattested (for example the sightline to the more distant fortifications than those in the immediate vicinity along the line of the Wall). It is also possible to prove that some earlier generalizations are not applicable to the whole system. For example, it was generally presumed that the fortifications along the Antonine Wall were built in order to have a good line of sight from one to another and that line of sight, in order to achieve it, was limited to the south. However, this is applicable "in general" only to the eastern section of the

Antonine Wall. The western forts usually had a far better line of sight to the south than to anywhere else, although this may not be the reason why they were built exactly where they were.

The second reason to work with Viewshed analysis instead of mere site-based observation is that the observer on the spot is usually able to describe what he sees from the place where he is standing but not the other way around. For the whole function of limes, it is always handy not only to describe what was achieved but also at the expense of what. For example, one has a fairly good line of sight from the fort at Bar Hill, especially to the north and west – on the slopes of Campsie Fells and into Kelvin Valley (**Fig. 1**: numbering of sites in the figures and plates refers to the list in the Appendix). However, the valley of Glazert Water to the north west and the area of Campsie Glen are invisible not only from Bar Hill but also from Auchendavy. In fact, the only fort, which had some line of sight to that area, was the Kirkintilloch, so the region was not totally omitted after all (**Fig. 15**).

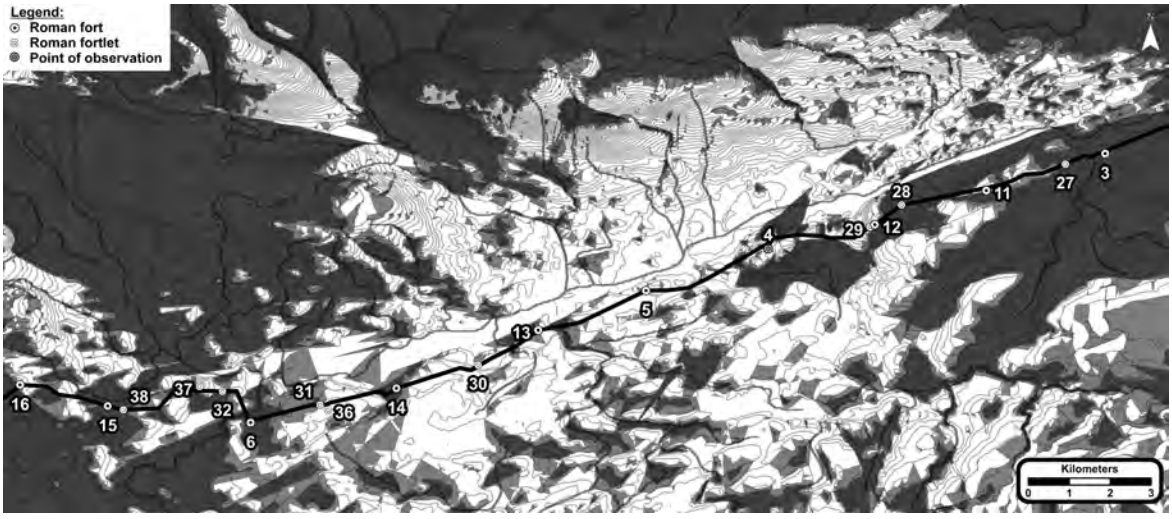

Fig. 1: Graphical representation of the area visible from Bar Hill [4] (slightly darker area visible only with applied offset B, dark area non-visible), map by author.

Those are just some results of the broader perspective through the Viewshed analysis, which are otherwise hard to classify by mere observation in the field. Work in an artificial environment also allows us to ask more hypothetical questions, e.g. what was the difference between the line of sight from a position elevated 5 m or 9 m above the ground. Were there some places on the frontier intervisible only from towers due to the difficult terrain? All in all, a chance to ask these questions (and find answers to them) shows that the Viewshed analysis can be, if performed correctly, with caution and with a bit of healthy scepticism, implemented on the problem of the layout of the Roman limes.

INTERVISIBILITY

The first issue that can be discussed with the Viewshed analysis is the topic of intervisibility of individual sites and parts of the Antonine frontier in Scotland. Were individual Roman installations on the Antonine Wall intervisible?

The conclusions are more or less in accordance with previous results (see Woolliscroft 1996, 153–177; Woolliscroft 2001, 153; Poulter 2009, 89–131), but they extend them in certain

ways. The author of this paper is not trying to address the theme of signal communication in general (comprehensively summarized in Woolliscroft 2001) but is mainly looking for an answer to the question whether the uttermost condition for the existence of any visual signal communication on the Antonine Wall was met. Were individual sites on this frontier intervisible to such a level that a continuous signal chain on the limes was maintainable in the form of simple beacons, as described by Woolliscroft (2001, 21–30)?

Forts north of the Antonine Wall were unsurprisingly not intervisible with each other, and with the exception of Camelon they could not have been connected to any kind of signal or visual communication chain on the limes (**Fig. 2**). In fact, it is immediately striking that Ardoch, Strageath and Bertha forts were situated on spots proximate to important rivers (it is questionable whether that was because of the anchorage ground or river crossings).

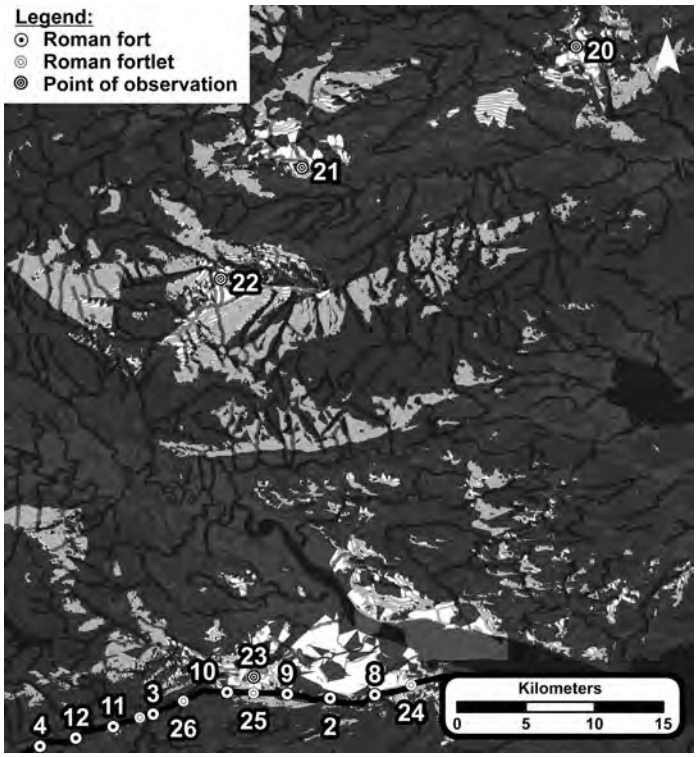

Fig. 2: Cumulative Viewshed of the forts north of the Antonine Wall (map by author).

The Viewshed from those sites offers quite illogical results, for example, not even the immediate surroundings of Strageath fort were visible for the potential Roman observers. The exact positioning of the fort was simply chosen for reasons other than sightline to the surrounding area.

The only exception is Camelon, situated more than 1 km north of the Antonine Wall (**Fig. 3**). Although its position gives excellent views to the mouth of the river Carron, the results of the Viewshed analysis indicate that the fort was intervisible with Watling Lodge fortlet directly to the south as well as with Kinneil fortlet (see also Appendix). The edge of the calculated sightline goes as far as to the exact position of two secondary forts, Rough Castle and Falkirk. One must stress that the line of sight ends in that direction precisely at the spot where those two forts are – not much more can be seen in the direction to the south east or south west. This phenomenon emerges in different ways on many other sites along the Antonine Wall – the line of sight from a fort ends precisely on the spot of another fort/fortlet.

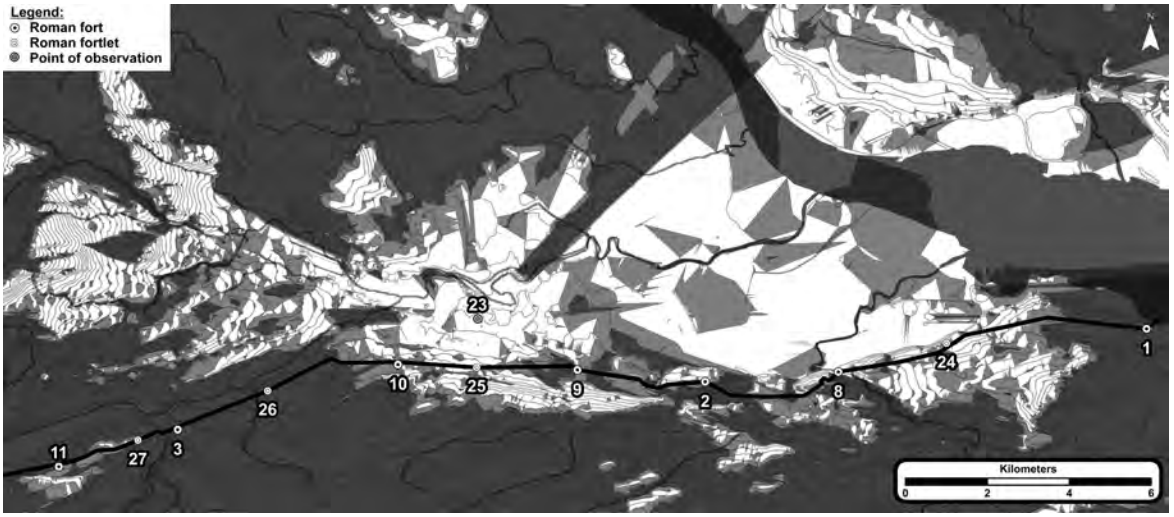

Fig. 3: Graphical representation of the area visible from Camelon [23] (map by author).

Camelon was also intervisible with one of the primary forts, Mumrills. The distance between them was more than 5 km and the forts' whereabouts are, as with the two previously mentioned, on the horizon of the possible line of sight. Camelon fort was also intervisible with the much farther secondary fort at Inveravon, however, the distance between them was more than 8 km and so it is questionable whether the direct sight link between them was intentional or indeed efficient.

Primary forts in general offered much better intervisibility results than those situated north of the Antonine Wall. Only two are, however, directly mutually intervisible (Bar Hill – Auchendavy). They usually had a direct line of sight to at least two other forts/fortlets, though, not always to the nearest ones. Exceptions were the coastal forts at Carriden and Old Kilpatrick, which will be discussed later.

Mumrills is intervisible with Inveravon, and from the western and northern gates of that fort the positions of Camelon and Falkirk forts could have been seen (**Fig. 4**).

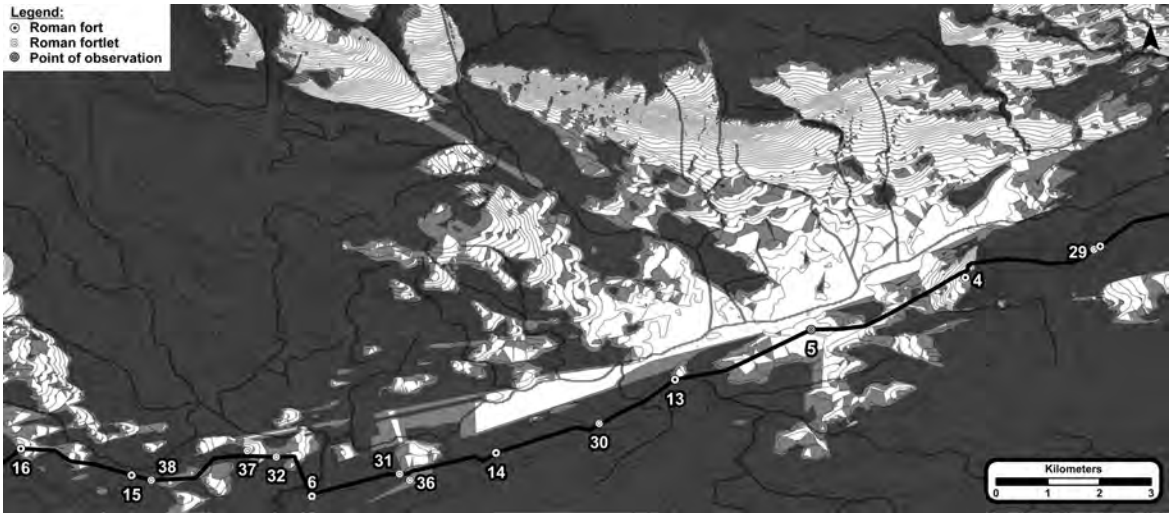

Fig. 4: Graphical representation of the area visible from Auchendavy [5] (map by author).

Castlecary is a bit of a worse example of intervisibility because it is only mutually intervisible with Seabegs Wood fortlet and possibly also with Rough Castle fort, which is on the edge of its line of sight (**Pl. 1/1**). The sightline to the west is blocked by the hill where the Garnhall tower was recently excavated (see also Woolliscroft 2008, 129–176).

The best spot for any signal communication or simple observation on the whole Antonine Wall lies unsurprisingly on the summit of Bar Hill (**Fig. 1**). It has always been puzzling why this fort was not placed directly on the line of the Wall but approximately 55 m to the south. In terms of the projected line of sight to the other Roman fortifications, it seems that the position a little bit to the south enables a view also to the south and most importantly to the east (the sightline to the west and north are superior by mere observation). If the fort had been adjacent to the Antonine Wall then the line of sight would have been obstructed by the prehistoric settlement site at Castle Hill. According to the calculation of the Viewshed analysis, from the top of Bar Hill's eastern gate the forts at Westerwood and Croy Hill could have been seen (in the present-day the sightline is obstructed by trees). Once again, the exact place where they were located is also the edge of the sightline in that direction. Rough Castle could also have been theoretically visible from Bar Hill, but the distance of more than 14 km makes this visual link very conjectural.

It is also important to stress what was visible from Bar Hill to the west. Apart from the already mentioned Auchendavy, Kirkintilloch secondary fort and the fortlets of Glasgow Bridge, Wilderness Plantation and Summerston were in the line of sight as well. The position of Castlehill fort could have been seen too, but the direct distance between Bar Hill and Castlehill is more than 18 km, which again makes this link highly speculative.

Auchendavy is intervisible with Bar Hill in the east and with Kirkintilloch in the west although the western connection is quite tight (**Fig. 4**). Balmuildy seems to be a badly positioned fort in terms of the Viewshed, nevertheless, its limited line of sight to the other forts was compensated for by two relays (fortlets), Summerston in the west and Wilderness Plantation in the east (see below and **Pl. 1/2**). The fort was intervisible with Castlehill secondary fort.

While the primary forts make a relatively coherent pattern (except Castlecary), the situation is different in the case of the secondary forts. Usually, the secondary forts are intervisible with one primary and one secondary. Nevertheless, sometimes the values are borderline (Appendix – Inveravon, Falkirk, Rough Castle, Westerwood, Croy Hill, Kirkintilloch). The exceptions are Cadder and Duntocher which are intervisible only with Castlehill.

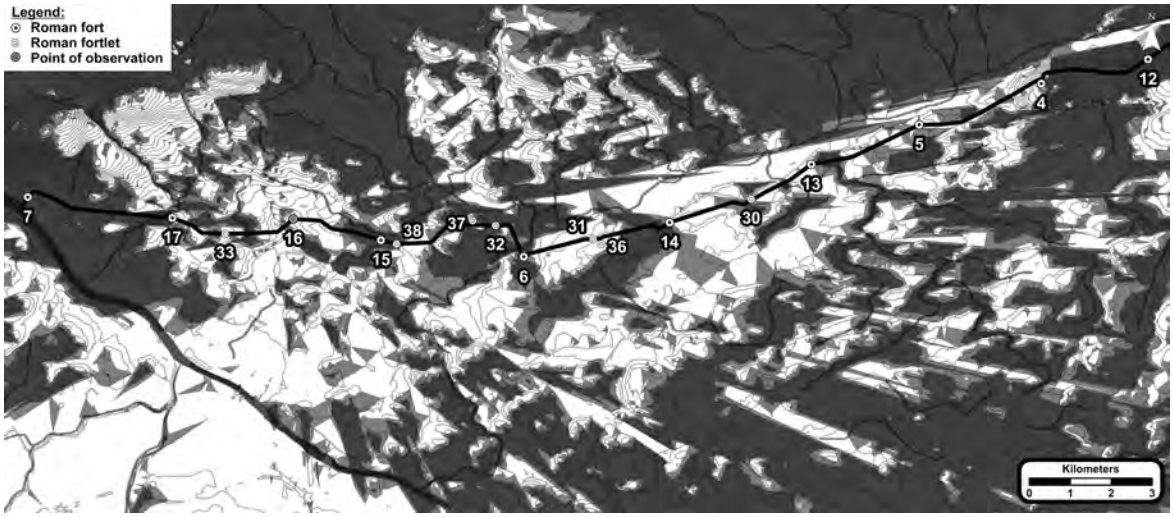

Fig. 5: Graphical representation of the area visible from Castlehill [16] (map by author).

Castlehill had a sightline to many other installations on the frontier, it is second in number of connections only to Bar Hill (**Fig. 5**). To the west, it is intervisible with Cleddans fortlet and Duntocher fort and in theory even with Bishopton. Just for the record, one could also see the place where the Lurg Moor seaside fortlet stood, it was 23 km to the west (an excessive distance for any kind of visual connection). But Castlehill is exceptional especially because of its sightline to the east – Balmuildy primary fort, Wilderness Plantation fortlet, Cadder secondary fort, Glasgow Bridge fortlet, Kirkintilloch secondary fort, Auchendavy and Bar Hill primary forts were all intervisible with Castlehill (the last two probably only in theory due to the excessive distance between them)!

Bearsden remains an enigma, since it was not intervisible with any other installation on the Wall (**Fig. 6**). Clearly, something is missing there, because unlike Castlecary, there is nothing in the line of sight of Bearsden that could serve as a potential relay (except a putative fortlet at Manse Burn). A possible explanation of this oddity will be discussed below together with the case of Balmuildy.

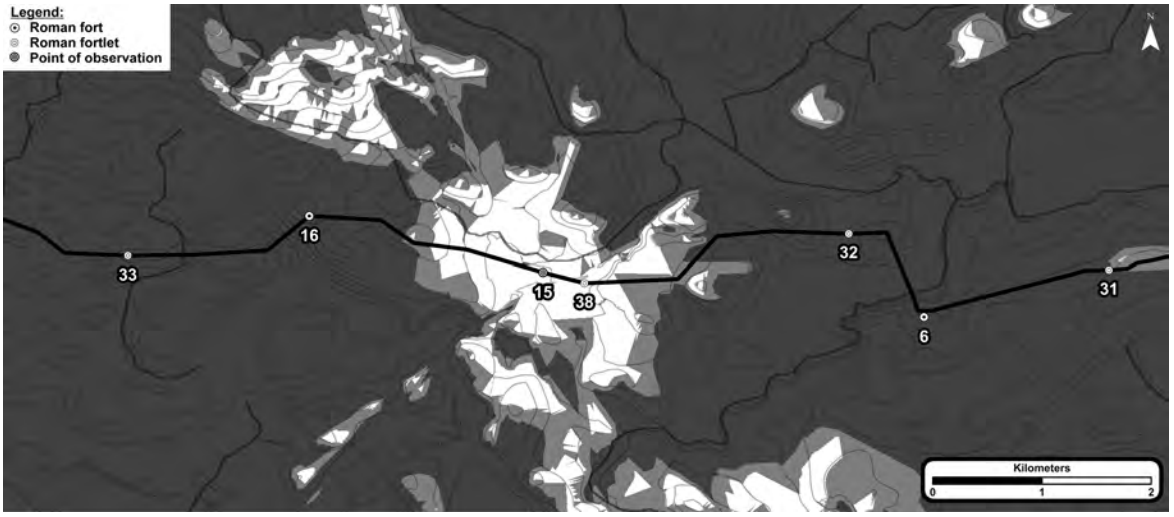

Fig. 6: Graphical representation of the area visible from Bearsden [15] (map by author).

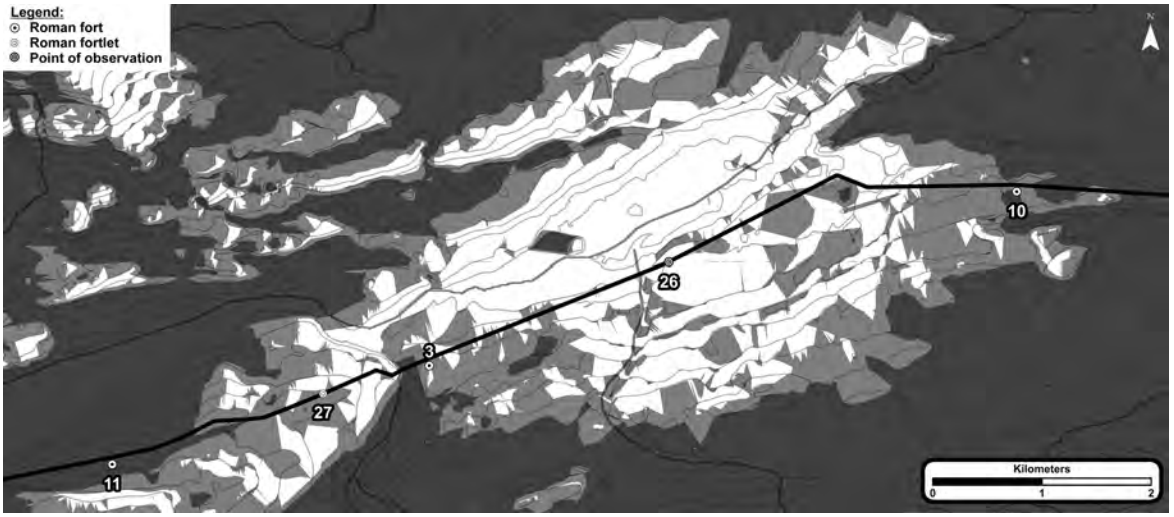

Fig. 7: Graphical representation of the area visible from Seabegs Wood [26] (map by author).

Fortlets are interesting especially as relays of potential signals from one fort to another. This is for example exactly what could explain the purpose of Seabegs Wood fortlet for Rough Castle and Castlecary forts, without which there would have been no connection (and thus the eastern section would have been separated from the central and western one: **Fig. 7**).

Similarly, Wilderness Plantation is intervisible with Balmuildy in the west and with Kirkintilloch 5.6 km to the east (**Pl. 1/2**). Surprisingly, there are no known relays to the isolated Cadder (except at the putative site of the potential fortlet at Cawder House, which lies directly on the edge of the line of sight of Cadder: **Fig. 8**).

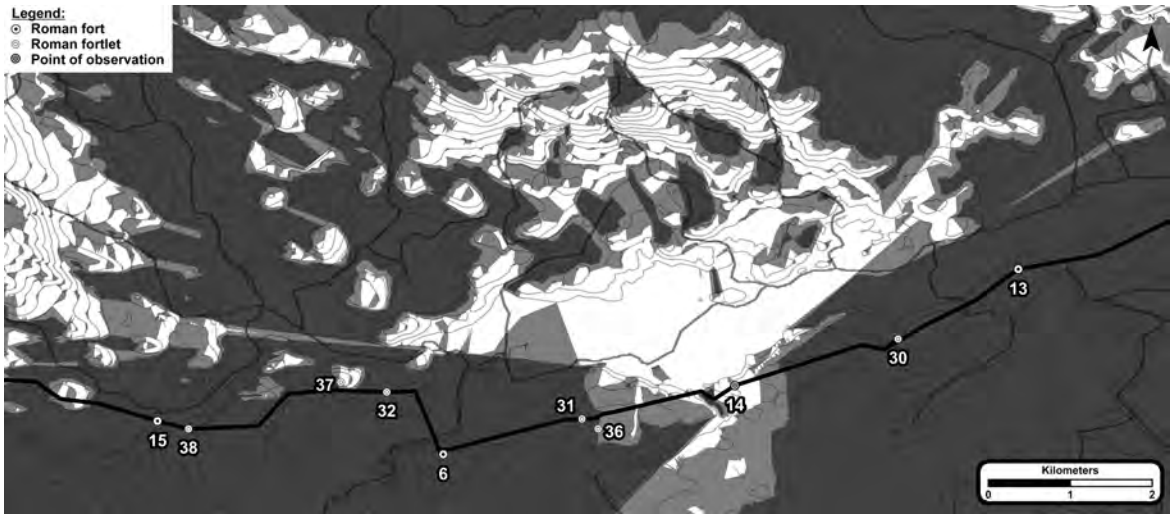

Fig. 8: Graphical representation of the area visible from Cadder [14] (map by author).

On the other hand, some fortlets seem to be superfluous as relays, for example Easter Dullatur lying between Croy Hill and Westerwood which are already in visual contact (**Pl. 1/3**). Glasgow Bridge fortlet seems to be redundant as well, since it is intervisible only with sites that are already in visual contact (Bar Hill, Kirkintilloch) and has no line of sight to the west where Cadder lies (**Fig. 9**).

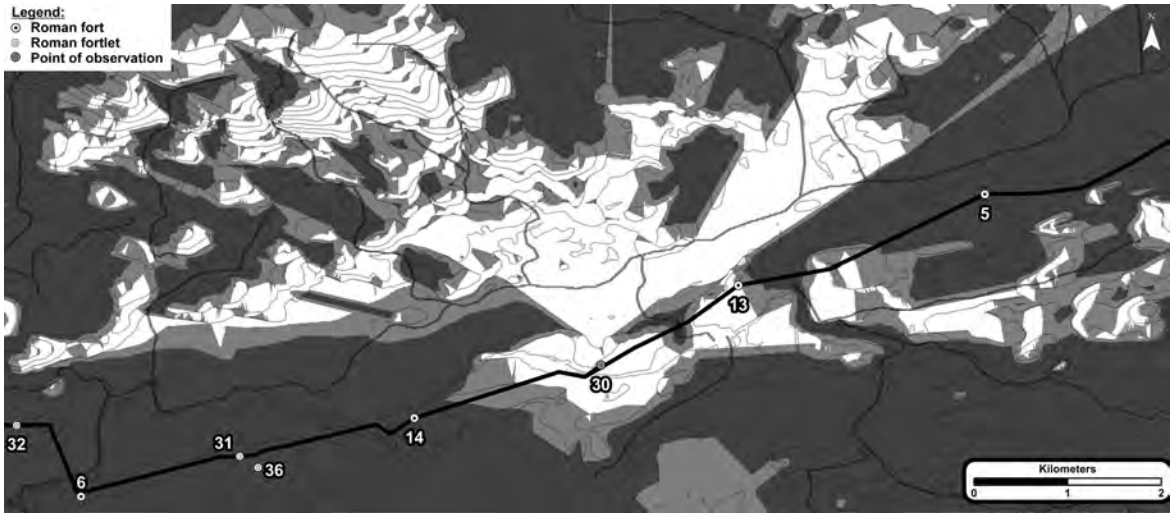

Fig. 9: Graphical representation of the area visible from Glasgow Bridge [30] (map by author).

Not to mention the Croy Hill fortlet which is in visual contact with exactly the same set of Roman installations as the 130 m distant Croy Hill secondary fort. In terms of the intervisibility of the forts, Cleddans fortlet could also be classified as redundant since Duntocher and Castlehill are only 3 km apart and already intervisible (the fortlet lies almost in the middle of them: **Fig. 10**). Either these duplicities make (in terms of intervisibility) the fortlets or the mentioned secondary forts redundant (see the Landscape observation from the chosen groups of sites).

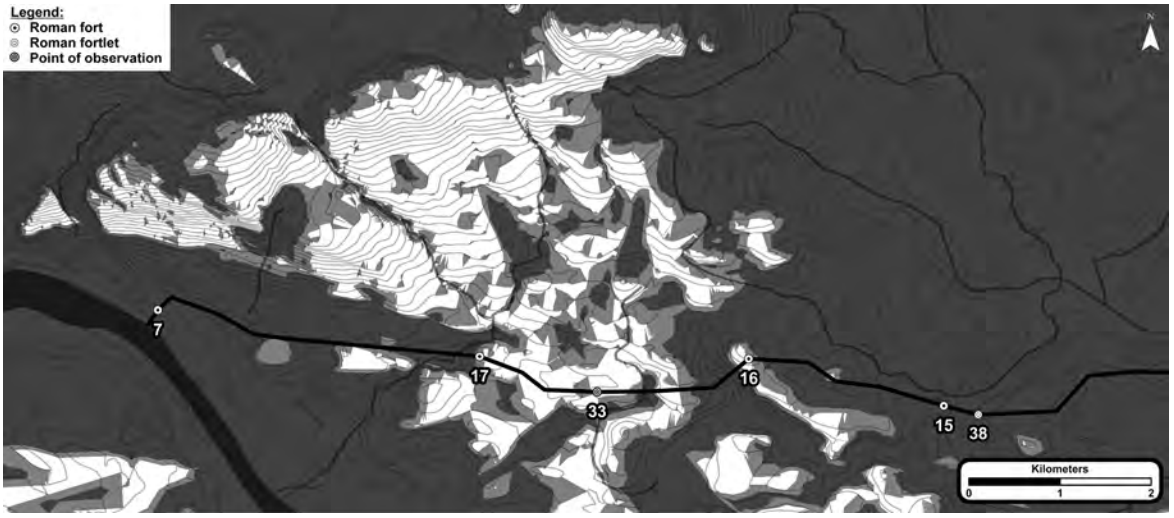

Fig. 10: Graphical representation of the area visible from Cleddans [33] (map by author).

The single most interesting line of sight of all the known fortlets is Summerston (**Pl. 1/2**). Since it has no line of sight to the west (although on the edge of its line of sight lies the putative Boclair fortlet which, however, even if proved to have ever existed, had no line of sight to Bearsden, the nearest fort), it was oriented solely to the south as a relay to Balmuildy. As previously mentioned, Balmuildy had a very limited line of sight, it was intervisible only with Castlehill. However Summerston was directly intervisible with both Auchendavy (10 km apart) and Bar Hill (almost 14 km apart), unlike the easterly lying Wilderness Plantation which on the other hand was intervisible with Kirkintilloch (6 km apart). Thus, with the use of two relays, Balmuildy fort, which at first glance looked like an isolated place (in terms of the intervisibility analysis), could have been in contact with Bar Hill, Auchendavy and Kirkintilloch (through fortlets) as well as with Castlehill (directly). The distances, though, are large and it is questionable exactly how there could have been such effective links (e.g. Summerston – Bar Hill).

Not much can be said about the intervisibility of the seaside forts and fortlets with each other or with other Roman installations. Cramond, standing alone in the mouth of the Almond, was out of any line of sight to the north west where the Antonine Wall lies (**Pl. 1/4**). Bishopton, on the other hand, was visible from several places along the western section of the Antonine Wall, namely from Castlehill and Duntocher, although, only the link with Old Kilpatrick was probably important. Lurg Moor fortlet seemed to be intervisible with the same sites as Bishopton but the distance to the nearest, Old Kilpatrick, exceeds 16 km. Outerwards fortlet is not intervisible with anything.

It is interesting to note that Bishopton fort was intervisible with neither one of the two seaside fortlets. However, if the fort had been moved some 100 m north (x:241908 y:672205) it would be intervisible with the Lurg Moor fortlet (though the distance between them would

still have been more than 12 km). The Romans evidently ignored that opportunity, so any possibility of signal communication with the seaside fortlets is highly speculative.

CONCLUSION I

To summarize the first issue of this paper (intervisibility and layout of the limes as a condition for military signalling), one can say that it seems that at least one of the requirements that soldiers building the Antonine Wall tried to fulfil was to place individual sites in order to make them intervisible. Much of this can be seen through site-based observation, but the connections were not always direct (Balmuildy and its links with other forts through fortlets: **Pl. 1/2**) and there may be some parts of that chain missing. The work in the 3D model shows us which sites were intervisible and which were not and it is easy to switch from one site to another to get a general overview. For this overview, see the Appendix.

It is possible to identify the sites with a great number of possible connections (and therefore probably nodal ones in an expected signal system like Bar Hill and Castlehill) as well as those marginal ones (for example Croy Hill, Cleddans etc.). In addition, it is obvious that the signal system could not operate along the whole line of the Wall – at least Carriden and Old Kilpatrick were not in any kind of visual contact with the inland part of the limes. Other sites seem to be partially omitted from the system, such as Cadder, or totally like Bearsden.

The single most important thing that the Viewshed analysis can tell us about the putative signal system on the Antonine Wall is the fact that quite a lot of sites were situated on the edges of the sightline of other forts. This is not so much evident by mere observation at each site, especially when the observer cannot make use of observation platforms on towers several meters above the ground. The number of sites that are intervisible in this fashion (sites mentioned in the Appendix as those with offB) is overwhelming. Trees or modern built-up areas nowadays obstruct some of those lines of sight but they can be reconstructed in a 3D model. It should be stressed that although the number of these "edge connections" is indeed great, not all of them were used or indeed planned. Sometimes distances are simply too great to allow them any kind of signal communication and one has to accept also the specificity of the local weather influenced heavily by the sea (Donaldson 1985, 19–24; Donaldson 1988, 349–356). However, some of these edge connections are of particular interest, for example between Camelon and Rough Castle (2.2 km apart), Mumrills and Falkirk (3.13 km apart), Bar Hill and Croy Hill (2.7 km apart), Bar Hill and Westerwood (5.5 km apart), Rough Castle and Seabegs Wood (3.2 km apart), Kirkintilloch and Auchendavy (2.8 km apart), Castlehill and Duntocher (3 km apart) or the absence of intervisibility with other forts in the case of Balmuildy which is substituted by the existence of two relays (from which, one of them, Summerston, is on the edge of the sightline from Balmuildy as well). The number of these "edge connections" is simply too high to be coincidental and it seems that one of the builders' designs was to have important parts of the frontier (forts) in visual connection.

Rough Castle serves as the best example of this phenomenon. This particular fort is positioned on the only small stretch of the Antonine Wall's line from which one could still have had an open view to the fort at Camelon to the north east as well as to the area of a primary fort at Castlecary, a secondary fort at Westerwood and a fortlet at Seabegs Wood in the west (**Pl. 1/5**). If the Rough Castle fort had been moved along the line of the Wall by some 150 m to the west or east, its intervisibility with either the western or eastern part of the frontier would have been lost. Indeed its position is the only one that allows the existence of any kind of potential signal chain on the Antonine Wall.

When intervisibility between forts was not possible for any reason, a relay was provided as was demonstrated in the case of Balmuildy. However, the case of Balmuildy also shows that not all hypothetical links could have been used in practice – it is probable that the link between Wilderness Plantation and Kirkintilloch and between Summerston and Auchendavy could have been effective, but the case of the Summerston-Bar Hill connection is speculative due to the excessive distance between these two sites.

LANDSCAPE OBSERVATION FROM INDIVIDUAL SITES

It is certain that individual forts and fortlets were not positioned on the Antonine frontier solely to fit the intervisibility pattern. Neither can this be proved by any means (despite good intervisibility of certain installations), nor is it logical for the Roman army to do so. Other requirements had to be fulfilled as well, e.g. control of free movement in the landscape or counterbalancing local security threats (we know very little about that in the mentioned period, see: Hunter 2007, 22–23; Ingemark 2014, 223–243; Wilson 2010, 32–36). It seems that one of the mentioned requirements was also to see what was going on north of the Antonine Wall. The Viewshed analysis can offer a schematic answer for a multitude of sites to a simple question. To which areas sentries in Roman forts and fortlets had the best view? How far could such an observation of the frontier be effective (where the line of sight usually ended)? What was blocking the view? Which areas were neglected and which were under surveillance from a multitude of sites?

A good point to start with is to describe what was visible from the best observation spot on the whole Antonine Wall, from Bar Hill (**Fig. 1**). Immediately to the north, the slopes of Campsie Fells and Kelvin Valley are visible. Farther to the east, the view is obstructed by the prehistoric settlement site at Castle Hill but one can see most of the area of present-day Kilsyth and in theory as far as to the village High Banton (more than 10 km in the north eastern direction). To the east, the sightline is more restricted and only Croy Hill fort and fortlet could be observable. To the south, the line of sight is good as far as to Mollinsburn village, roughly 8 km in a beeline from Bar Hill. To the west, the line of sight is good as far as to the 15 km distant village of Torrance and spots of several Roman sites in that direction are visible as well as the broader area north of the Antonine Wall. In a direction that is more northerly, the line of sight ends with the location of Lennoxtown and again with the peaks of Campsie Fells. All in all, Roman observers from four towers at the gates of Bar Hill had a good line of sight to the impressive area of 420 square kilometres (see also the Appendix where the values of the area visible in a 10 km perimeter are offered for Bar Hill and other forts and fortlets), roughly taking a shape of an ellipse covering a better part of the Forth-Clyde isthmus. No other fort had such a good line of sight to its surrounding area.

From the site of Mumrills fort an observer had a limited line of sight only to the positions of neighbouring forts (even those values are borderline) to the west and east (**Fig. 11**). The only good line of sight is to the north, to the Firth of Forth and in the inland area as far as to the northern fringes of the present-day towns of Stenhousemuir and Airth Castle.

Auchendavy had no line of sight to the south and only a limited one in the north western direction (**Fig. 4**). The Kelvin Valley is visible from this fort, however, nothing more that can be already seen from Bar Hill is visible from Auchendavy. Balmuildy has no line of sight to areas other than its immediate perimeter of less than 2 km around the fort (**Pl. 1/2**).

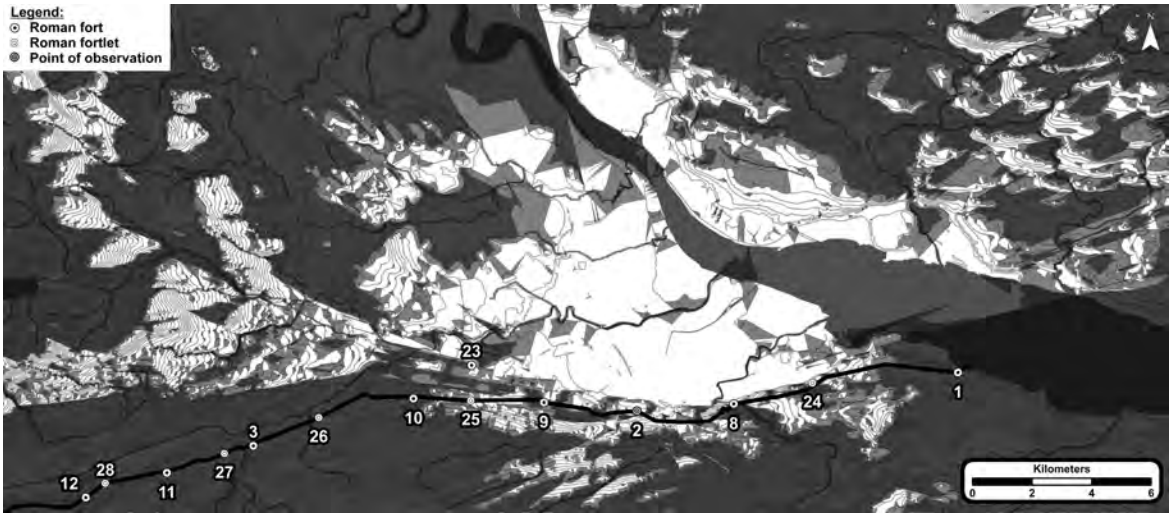

Fig. 11: Graphical representation of the area visible from Mumrills [2] (map by author).

Before proceeding to the secondary forts, Carriden and Old Kilpatrick can now finally be discussed. As mentioned above, they have no line of sight to other forts and fortlets on the Antonine Wall. In fact, they have no line of sight to the land part of the whole frontier region (around the Antonine Wall and immediately to the north). Both Carriden and Old Kilpatrick are facing the coastline or, to be more precise, they are oriented to the estuaries of the Forth and Clyde respectively (**Pl. 1/4**). The sightline from Carriden covers roughly the shore between present-day Kincardine and North Queensferry villages where the Forth Road Bridge now lies. The visual edge of sightline from Cramond fort starts precisely at the position of North Queensferry and goes as far as to Kinghorn village, some 12 km to the north east of the fort's position.

While the plan to cover by sight the whole coastline is obvious in the east, the situation is more tangled in the west. Roman observers from Old Kilpatrick had almost no line of sight on the shore behind the line of the Antonine Wall. Although the position of the fort gives an excellent view of the estuary of the Clyde and the left bank of this river, a true sightline to the projected non-Roman coast incorporates the seaside fort Bishopton. From this spot, the potential observer sees the whole coastline between present-day Kilpatrick and Cadross villages with a particularly good view to the estuary of Leven.

The observed area is largely duplicated by the view from Lurg Moor fortlet, which besides already mentioned, also has a good view of Gare Loch and Rosneath peninsula shores. The next seaside fortlet, Outerwards, is on a good spot to observe the south eastern shores of Cowal peninsula, the Isle of Bute and the island of Great Cumbrae. There is a gap between Lurg Moor and Outerwards that leaves a 5 km broad and almost 10 km wide stretch of the Firth of Clyde between Cowal peninsula and the shore of the Central Lowlands unobserved. It is interesting that almost the whole eastern shore of Cowal Peninsula is visible when we combine the line of sight from both fortlets but the water surface remains in shadow. It is questionable whether that was intentional and the observation of land was enough for the Romans, or, whether one fortlet somewhere between those two mentioned is missing to give a complete picture. A possible explanation could be found via a combination of Viewshed and Cost path results, discussed further below.

The area observable from the secondary forts varies. Three have a very poor line of sight to the surrounding area (Cadder, Bearsden and Duntocher), two on the other hand were evidently

built on spots with a good overview of the surrounding panorama (Kirkintilloch, Castlehill). The remaining five proved to be somewhere in between.

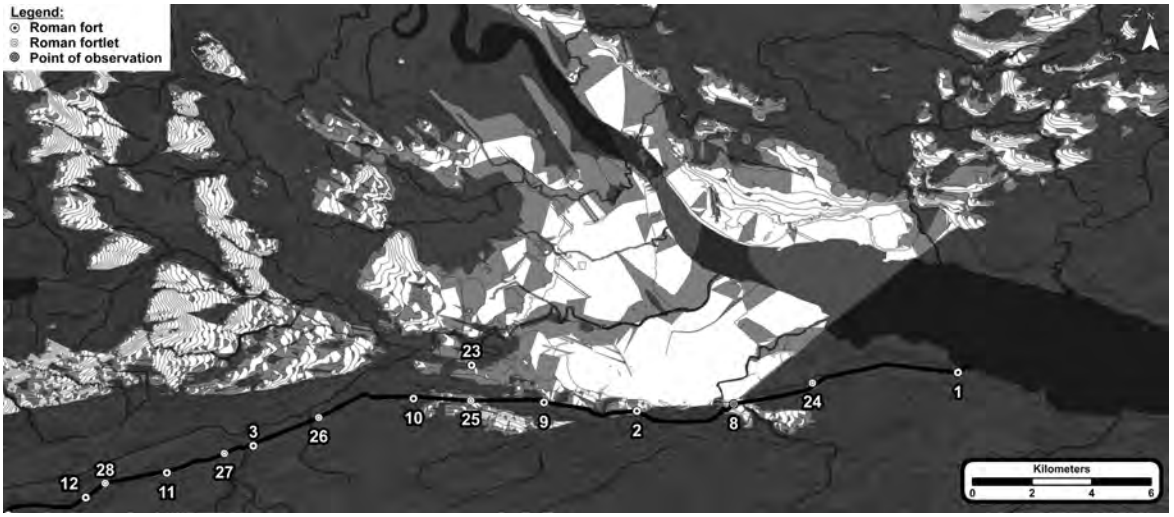

Fig. 12: Graphical representation of the area visible from Inveravon [8] (map by author).

The geographical distribution of the afore-mentioned subcategories is interesting too – these, whose line of sight could have been described as "average" are all situated in the east – Inveravon (**Fig. 12**), Falkirk (**Fig. 13**), Rough Castle (**Pl. 1/5**), Westerwood and Croy Hill (**Pl. 1/3**). These five forts have another common denominator – almost no line of sight to the south. Inveravon, Falkirk and Rough Castle are instead solely oriented to the north. The area, which could have been observed from them, can be described as the broader surroundings of Camelon fort. Westerwood and Croy Hill in the more central part of the Antonine Wall line have a good view to the slopes of Campsie Fells and Kelvin Valley to the north but again almost no line of sight to the south. From all the mentioned forts, a broader overview to their western and eastern surroundings was obstructed, although the intervisibility between them was maintained (see Appendix).

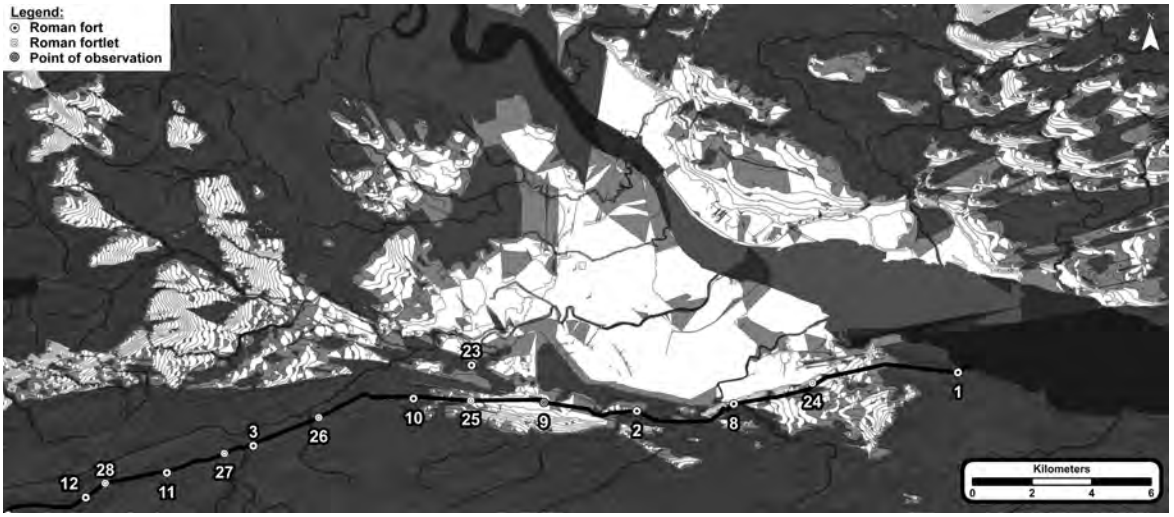

Fig. 13: Graphical representation of the area visible from Falkirk [9] (map by author).

The remaining five forts do not represent a coherent pattern. Cadder, Bearsden and Duntocher have a poor line of sight in comparison with other installations on the frontier. Cadder is somehow similar to the eastern secondary forts because its line of sight is again unobstructed to the north and the fort has a good line of sight to "its" section of the Kelvin Valley (**Fig. 8**). But to the east, west and south, only a small perimeter remains under observation from that fort. Bearsden is slightly better with some line of sight to the east and west but its line of sight to the north and south is obstructed (**Fig. 6**). The positioning of this fort seems to be rather odd, further explanation is offered below.

Duntocher secondary fort, originally preceded by a fortlet, has a slightly better line of sight to a 10 km wide perimeter of the surrounding area (see Appendix) but contrarily to the eastern forts, most of what could be visible from that site is in the south and it is questionable whether that was the Roman intention (**Fig. 14**).

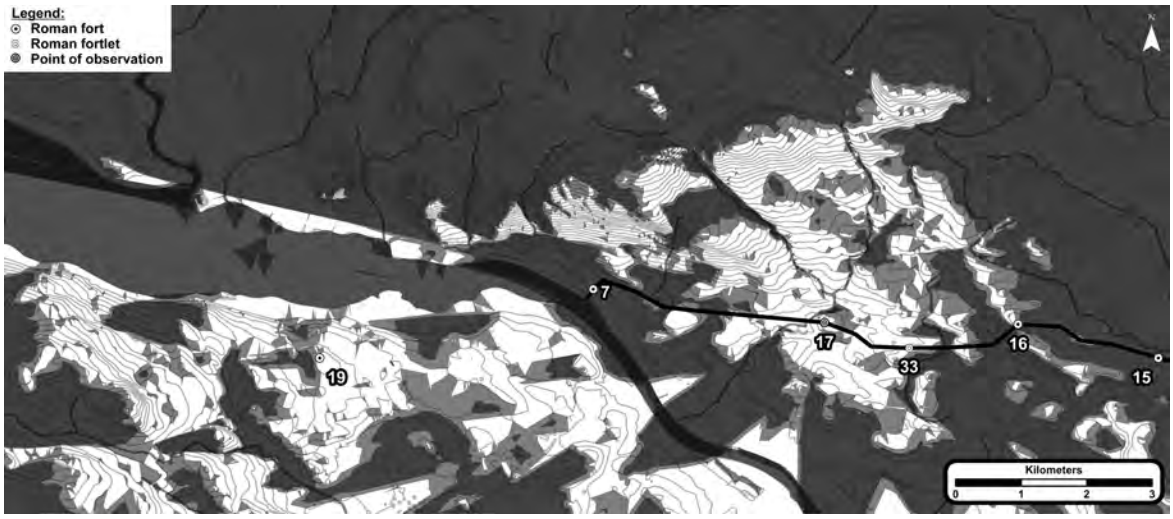

Fig. 14: Graphical representation of the area visible from Duntocher [17] (map by author).

Two secondary forts remain to be described, Kirkintilloch and Castlehill. The first one is special because it has a good line of sight to all directions in more than a 3.5 km perimeter except to the east (**Fig. 15**). Therefore, it is not solely oriented to one direction as the eastern forts are. Otherwise, although its sightline also gives a good coverage of the area between Auchendavy and Cadder, in total numbers its sightline covers only 65 km in a 10 km square perimeter. That could be classified as "below average" when the fort did not provide a line of sight to the areas where not even the two best positioned forts on the Antonine Wall (Bar Hill and Castlehill) could not see, like the valley of Glazert Water, Campsie Glen and Red Burn.

Castlehill is a far better example of a fort with a good line of sight to the frontier area. In a theoretical 10 km perimeter around the fort, the area, which could have been seen from the fort, was more than 184 square kilometres. Although this number sounds formidable, in fact most of the mentioned area is in the south western direction, south of the Antonine Wall (**Fig. 5**). It was already mentioned that the fort could have been in visual contact with many other forts and fortlets on the line of the Wall, however, the sightline to the area north of the Antonine Wall is not so formidable as it is in the case of Bar Hill. To the north west, the sightline from the fort covers the north western part of present-day Duntocher and the slopes of the Kilpatrick Hills. To the north and immediate east, most of the present-day Bearsden is visible, except the whereabouts of the eponymous Roman fort. In the north eastern direction,

the sightline goes as far as to the position of the present-day hamlets of Mugdock and Blairskaith. One could have seen from Castlehill the line of the Antonine Wall theoretically as far as to Twechar (more than 30 km away) near Bar Hill. The superiority of sightline to the south western and south eastern regions is evident from the visualization but it is questionable whether all that was an intention.

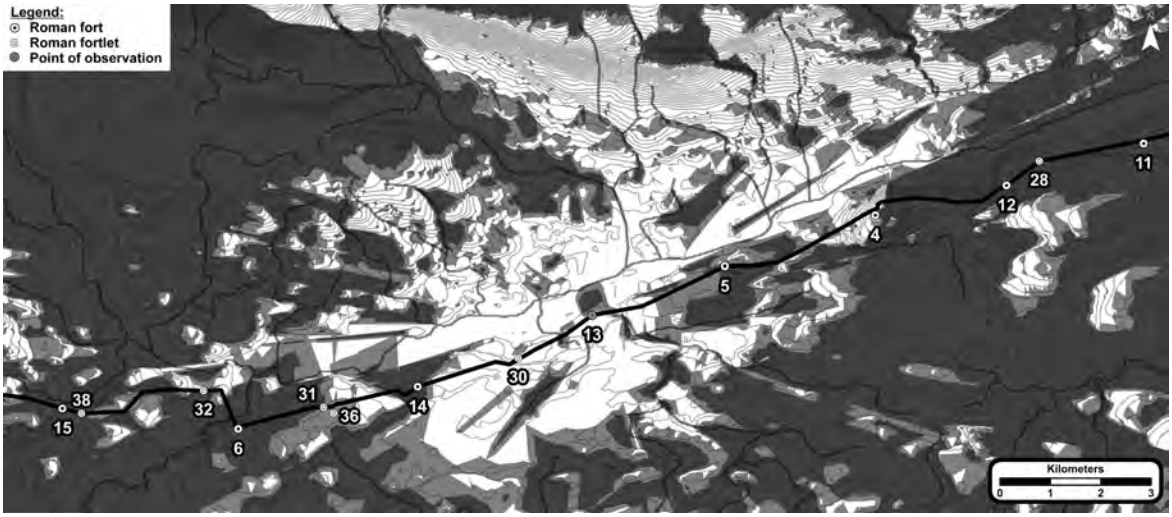

Fig. 15: Graphical representation of the area visible from Kirkintilloch [13] (map by author).

The overall sightline to the frontier region from the fortlets varies considerably. Only Wilderness Plantation had a good line of sight to the broader area having a view as far as 8 km off its position to the north eastern outskirt of present-day Torrance village in the east and Mugdock hamlet in the north (**Pl. 1/2**).

The area that could have been seen from the three most eastern fortlets (Kinneil, Watling Lodge and Croy Hill) is more or less similar to what could have been seen from the nearby forts (respectively Inveravon, Camelon and Croy Hill). Apart from them and Wilderness Plantation, all the other remaining fortlets had a very poor sightline not only to the frontier region but in general. The area that could have been observed from the Seabegs Wood fortlet forms in the map only a 4.6 km wide elliptical section (**Fig. 7**). Easter Dullatur has a good line of sight to the north east to a 3.5 km wide stretch of the Kelvin Valley but has no line of sight in any other direction beyond that except to the Croy Hill fort/fortlet (**Pl. 1/3**). The area that could have been observed from the Croy Hill fortlet is almost the same as the area visible from Croy Hill fort which makes this site exceptional among the other fortlets and redundant in the observation of the frontier region as well. Glasgow Bridge fortlet is positioned on a spot from which a 3.5 km wide stretch of the Kelvin Valley is visible and not much else (**Fig. 9**). The area that could have been seen from Summerston fortlet makes no coherent pattern and no significant part of the frontier area could have been seen from this site (**Pl. 1/2**). The result of the Viewshed analysis also shows that almost the same could have been seen from Cleddans fortlet and Duntocher fort and fortlet (**Figs. 10** and **14**).

LANDSCAPE OBSERVATION FROM THE CHOSEN GROUPS OF SITES

Before proceeding to the conclusions, another feature offered by the work with Viewshed analysis can be discussed. One way to work with the above presented data is to create a cu-

mulative Viewshed of a multitude of chosen sites on the frontier area and then study whether sight to some areas was not omitted or to the contrary, whether there was any duplicity and principally what a bigger picture of the whole frontier observation could look like.

From the primary forts together, the observers had an excellent overview of the frontier region in the eastern and central section of the Antonine Wall, mainly because of the excellent positioning of Bar Hill and Mumrills (**Fig. 16**). The west was on the contrary highly problematic especially because of the sightless Balmuildy. Evidently, any system of observation of the frontier area was not projected to stand solely on the good positioning of the primary forts.

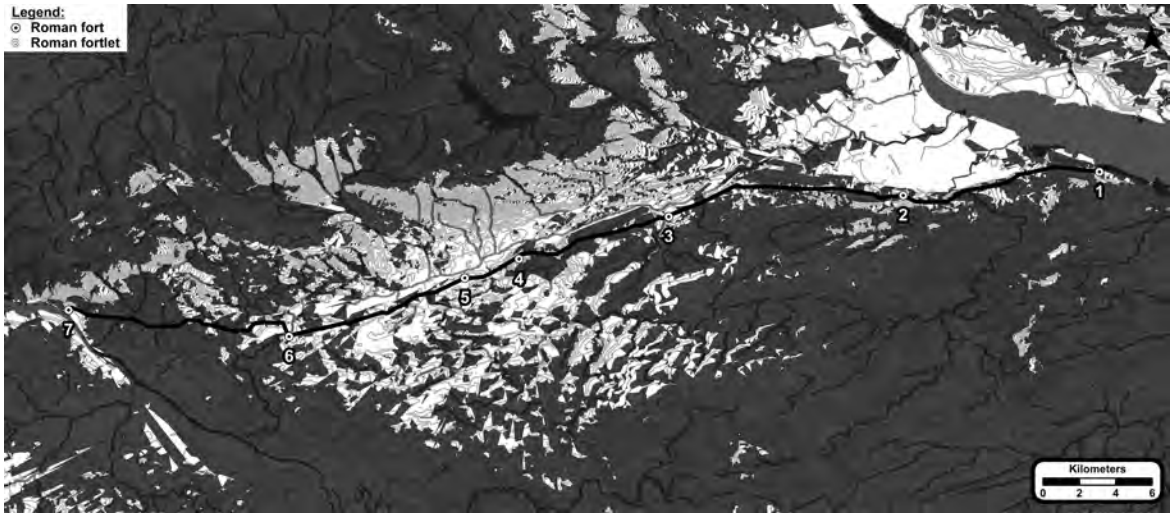

Fig. 16: Cumulative Viewshed of the primary forts. All noted sites are points of observation (map by author).

If we take the secondary forts as an independent group (although they were not) we can get slightly better results. When the sightline from all ten forts is combined, the whole frontier area seems to be under surveillance except the immediate endings of the Antonine Wall in the east and west. The secondary forts are more equally spanned but the intervisibility between the individual sites is often in edge values or through relays of fortlets and primary forts.

Since the sightline from fortlets does not make any coherent pattern, there is no reason to treat them (not even in theory) as an independent group that could be discussed alone. It is more promising to combine their line of sight with the sightline of the primary forts and Camelon. Combined together, nine fortlets and in fact only six forts (the sightline from Carriden and Old Kilpatrick primary forts is limited in the hinterland direction and Camelon is added instead of them because of its proximity to the frontier) make a much more coherent pattern (**Fig. 17**). In the eastern section, the already good results of the sightline from Camelon and Mumrills are backed up by Kinneil and Watling Lodge fortlets. In the central section, the area observed from Castlecary is only duplicated by what could have been seen from Seabegs Wood fortlet. Next in the course of the Antonine Wall is a 9 km wide gap between Castlecary and Bar Hill in a rather difficult terrain. The observation from this area is not ideal from Croy Hill and Easter Dullatur fortlets but the intervisibility of individual sites is at least maintained even without Croy Hill and Westerwood secondary forts (the only gap is between Castlecary and Easter Dullatur which is described in the example below, see Garnhall). The rest of the central section was under an excellent view of the Bar Hill and Auchendavy forts despite the fact that Glasgow Bridge fortlet was not on a good spot to observe the frontier area. Standing

alone, Balmuildy fort is problematic for the surveillance of the western section. With two relays, as already mentioned above, signal communication (Summerston) and a general view to the countryside (Wilderness Plantation) were maintained. The westernmost section could be under visual control from Cleddans fortlet that offers in terms of Viewshed analysis similar results to the Duntocher secondary fort under which the foregoing fortlet originally stood before the construction of a fort (Robertson 1957, 16–33).

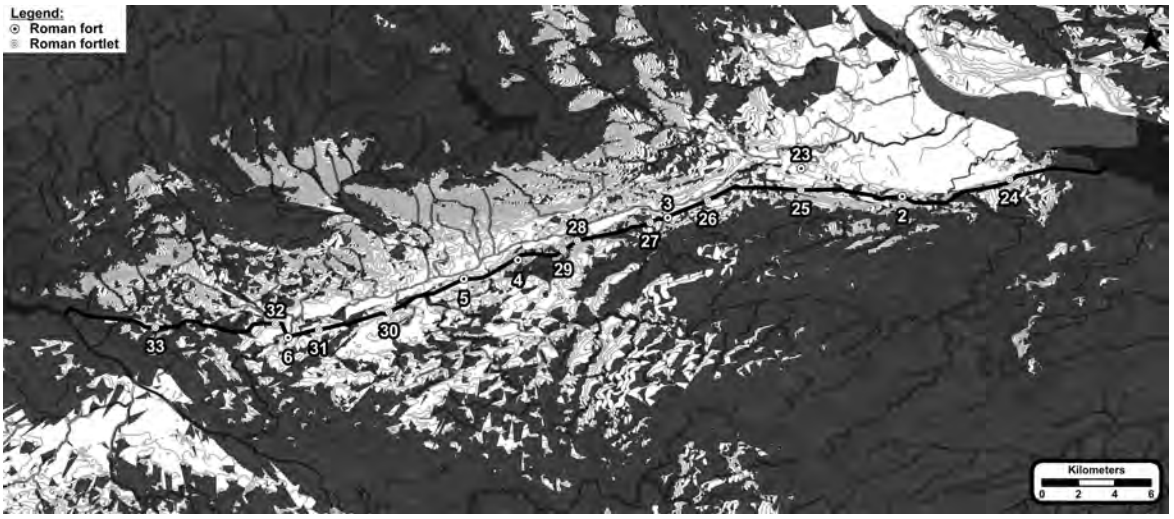

Fig. 17: Cumulative Viewshed of the Camelon fort, fortlets and primary forts without Carriden and Old Kilpatrick. All noted sites are points of observation (map by author).

COST PATH ANALYSES

Before presenting the conclusions, one more aspect should be discussed. It is apparent that despite many sites on the Antonine Wall seeming to be positioned in order to fit a visibility and intervisibility pattern, some forts simply do not fit into this system at all. Principally, these sites are secondary forts at Bearsden and Cadder, but one could also add the primary fort at Balmuildy among them, since its positioning is simply unfavourable, despite being counterbalanced by the existence of two relays – the fortlets at Summerston and Wilderness Plantation.

It is immediately tempting to describe the positioning of these sites vaguely as "strategic", alternatively to presume that they were located on "natural blocking points" or "near the vital river crossings". However, these functions can be verified (to a certain degree) via simulation in an artificial environment. Using the already presented digital elevation model, one can perform a so called Cost path analysis, which with the spatial use of several algorithms calculates the most affordable or least demanding path through the landscape from one point to another. Running this analysis for a multitude of sites can thus point out a certain area where a great assemblage of potential routes meet. Such a natural junction can thus be considered as an ideal blocking point or a good place to position a garrison. This suggestion works on the assumption that on the basis of day-to-day practice, people tend to choose the least demanding/most affordable path for their travels and the Romans knew the courses of these paths or tracks when they chose places for permanent installations on the limes.

This approach is of course highly speculative and theoretical for obvious reasons. Just because a path is convenient by the absence of great elevation differences (e.g. slope) does not

mean that somebody actually used it. But if we accept the fact that certain tracks or roads were used for movement in the landscape, the least affordable routes seem to tempt more traffic than those more inaccessible. Therefore, the results of cost path can be taken as a sort of hint or a scenario probable more than the others.

The question is: why were the mentioned forts positioned where they were in the first place? Was one of the reasons an attempt to position a garrison on a spot where it could block (and thus regulate) free movement in the landscape?

Evidently, the location of Balumildy was not chosen haphazardly. The fort itself was built before the actual construction of the the Antonine Wall (Miller 1922, 4–15) and the Wall builders had to move southward to reach the position of this site. From Balmuildy, the Antonine Wall continued to the north west to reach the fortlet at Summerston. Clearly, the position of Balmuildy was important enough to abandon the straight course of the Wall and reshape the frontier line to fit the positioning of Balmuildy.

Cost path results show that the fort was built directly on a spot where the most convenient route from the Iron Age settlements north of the Antonine Wall crossed the course of the limes on its way down to the south (**Pl. 1/6**). This conclusion is based on the results of a Cost path analysis which tried to determine the most convenient route between the locations of numerous Iron Age settlements north of the Antonine Wall and the valley of the Clyde, a gateway to southern Scotland and thus the hinterland of the Roman province in the 2nd century AD. For the absolute majority of native sites, the route led through the position of Balmuildy and it was visible from this site as well.

It is even more interesting, however, that the only exceptions were the westward-located sites. From those it would be easier to go through the position of another fort at Bearsden. This fort was until now at least as enigmatic as Balmuildy. Bearsden was also not intervisible with other forts and fortlets (see above and **Fig. 6**). Despite being unfavourable in many ways, the fort at Bearsden stood in an excellent position to block any traffic going south from the area of Kilpatrick Hills (cf. below and Poulter 2009, 108).

Cost path can be also used to determine the direction of a road that probably existed but its course is currently unknown. Stretches of road connecting Roman military installations on the Antonine Wall have been known for a long time and the general course of this road can thus be postulated (Macdonald 1934, 96–189). However, the situation is more tangled with the seaside forts and fortlets. While the course of the eastern road, roughly moving northward from Newstead to Cramond and then possibly to an eastern fort, is known (Margary 1973, 466–469), the western branch remains enigmatic. No doubt, a certain road connected the seaside fortlets to each other. Cost path analysis can, in this case, be used to suggest the most convenient course for such a road. The resulting most affordable route (**Pl. 1/7**) goes through several spots where a road, possibly Roman, was surveyed in 1963 (Newall 1963, 43), 1970 (Newall 1970, 12–13, 43) and 1984 (Newall 1984, 32). The road suggested via cost path analysis and previously observed by Newall goes through Loch Thom, an artificially constructed reservoir from the first half of the 19th century.

On the other hand, traces of a possible Roman road were also documented further to the west (Newall 1963, 43; Newall 1988, 24–25). However, this road would be more effortful, longer and with more river crossings. The existence of another fortlet could be a justification for such a solution. Still, the structure on Hillside Hill, suggested by Newall (1963, 43), shows no signs of Roman origin, has no line of sight to Lurg Moor or Outerwards (it lies outside their line of sight) and most importantly, has no view of the area of the outer Firth of Clyde. It is therefore, questionable to what good such an outpost would be. In fact, a spot with a good line of sight to the coastal area and nearest to the postulated road course lies on the so-called Dunrod Hill,

some 650 m westward. Traces of a possible Roman road were surveyed near this hill (Newall 1988, 24–25) and thus a theory about the existence of another fortlet between Lurg Moor and Outerwards is not entirely irrelevant, but without any new evidence of the existence of a westward Roman road and fortlet with a (limited) line of sight to the outer Firth of Clyde is conjectural. Traces of possible and undated roads have no coherent pattern, archaeological evidence for the existence of a fortlet is almost none despite the fact that it would be logical and handy to outpost a detachment somewhere between Lurg Moor and Outerwards fortlet and thus have the whole Firth of Clyde under the line of sight. This is handy from a theoretical point of view and it would fit well into what has been presented about the Antonine Wall forts and fortlets so far. However, with current evidence it seems that surveillance from two known fortlets was enough for the Romans and a road linking the two known fortlets followed more or less the least cost path as presented on **Pl. 1/7**.

CONCLUSION II

The presented results show that primary forts with fortlets could have had good visual contact with the landscape of the frontier region of the Antonine Wall (**Fig. 17**). The majority of sites were intervisible with their immediate or farther neighbours (see Appendix). It is very probable that some of the fortlets, which were originally part of the frontier system, escaped our notice and are now lost and therefore not included in the analysis. Knowledge of their original whereabouts could give us a better picture but even the few known ones together create an interesting chain of surveillance of the frontier region. It is remarkable how few gaps in this potential system can be observed.

If we add to this already functional layout the group of secondary forts, then we can see that the area covered by the surveillance of the primary forts and fortlets does not significantly grow, only the amount of duplicities rises (**Fig. 18**, compare with **Fig. 17**). What on the other hand is more apparent is the limit of the sightline from all the forts when the Viewshed of a multitude of sites is combined. The average distance between the fort/fortlet and its edge of sightline to the north is about 6 km as the crow flies. While in the eastern section the results go as far as to 8 km, the central area of the Antonine Wall is naturally determined by the Campsie Fells, so that the distances between the forts and the edge of their sightline is around 5.5 km. In the west, the figures go down because of the proximity of Kilpatrick Hills, so that a potential Roman observer from Castlehill fort could see as far as to the area of Windyhill Golf Course which was some 1.5 km in distance to the north from his position. In general, potential sentries in Roman forts had an excellent overview of the surrounding landscape, especially to the area north of the Antonine Wall.

This paper does not try to offer a definitive answer to the current debate whether secondary forts were secondary only in construction or in intention as well. However, the visibility study offers a chance to add a few observations on this topic. First is the case of Croy Hill where a fort and fortlet are situated nearby. In both landscape observation and intervisibility the fort or fortlet separately are enough for this area and there is no reason for duplicity (Graafstaal *et al.* 2015, 64). The existence of a certain Roman military installation at Rough Castle was imperative for both visual contact between the eastern and central part of the Antonine Wall as well as for the landscape observation in general. If any signal communication line was ever planned on the Antonine Wall, it could not have been effective without the existence of a relay at Rough Castle, which as mentioned above, was perfectly positioned to fulfil such a role. The same can be said about Bar Hill. On the other hand, certain forts could have been added to

the frontier system later to fulfil a blocking function across the Antonine Wall regardless of any spacing formula or visibility matters. An excellent example of this is the fort at Bearsden.

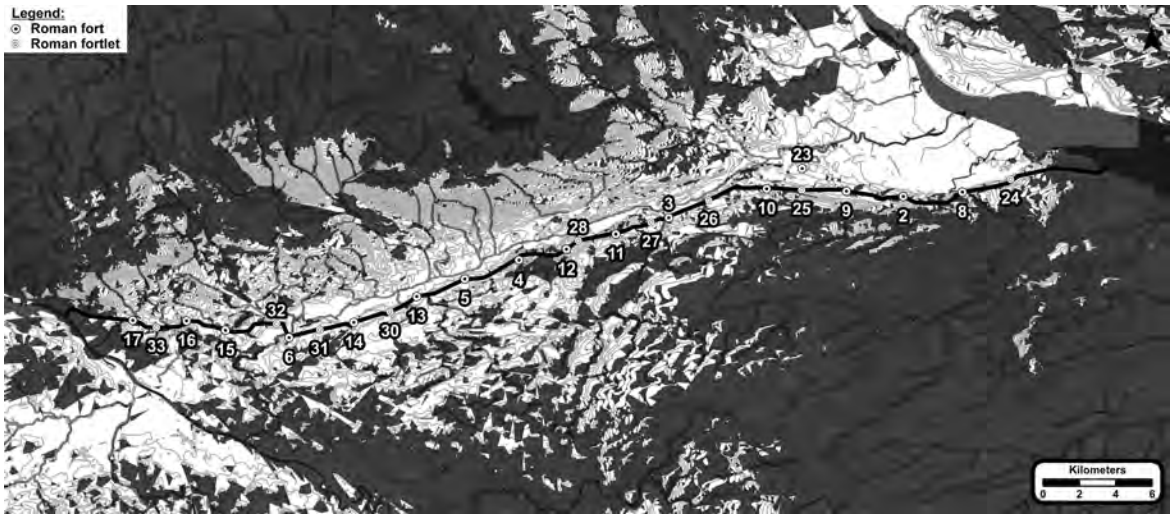

Fig. 18: Cumulative Viewshed of the Camelon fort, fortlets, secondary forts and primary forts excluding Carriden and Old Kilpatrick. All noted sites are points of observation (map by author).

A conclusion about the intervisibility of forts and fortlets along the frontier on the basis of Viewshed analysis can be that it could be maintained to a certain level. With the support of secondary forts it was definitely feasible. Without this support, it could be maintained as well, but with some difficulties. If we presume that only primary forts and fortlets existed at least for a while (or alternatively the frontier system was planned to run like that), the system could still operate. The potential gaps in the system without secondary forts are between Seabegs Wood fortlet and Walting Lodge fortlet/Camelon fort and between Castlecary fort and Easter Dullatur/Croy Hill fortlet (Carriden and Old Kilpatrick forts are not included). If we add the secondary forts to the system, then the first mentioned gap is filled by Rough Castle (**Pl. 1/5**). As mentioned above, the position of Rough Castle is unique especially as the only place with a line of sight to both the eastern and western section of the Antonine Wall.

Only one gap remains between Castlecary and Westerwood which could be filled by the existence of a relay at Garnhall standing on the edge of the sightline from Castlecary. The tower or fortlet would have to have been more than 9 m high (the position of Garnhall is approximately 90 m.a.s.l., the hill obstructing the view directly is more than 100 m.a.s.l. and Westerwood itself is approximately 105 m.a.s.l.). If we accept the presumption that Garnhall was a tower (based on the conclusion of the excavator: Woolliscroft 2008, 163), the theoretical line of sight from this site includes not only the secondary fort at Westerwood but also a fortlet at Croy Hill that probably preceded the secondary fort nearby (**Pl. 1/1**). This points once again to the fact that intervisibility between individual sites on the Antonine Wall could have been maintained even without secondary forts.

In the west two problematic places remain, both in terms of visibility of landscape and intervisibility with neighbouring sites. These are the secondary forts at Cadder and Bearsden. A system of potential signals could have existed even without connection with those two forts because Kirkintilloch was intervisible with Wilderness Plantation (overlapping Cadder) which was in the line of sight from both Balmuildy and the farther Castlehill (overlapping Bearsden: **Fig. 15**, **Pl. 1/2**). New discoveries may prove that the two mentioned forts could have been part

of the potential system of signal communication after all by the existence of relays, as we can see in the case of Balmuildy.

The position of the fort at Balmuildy was chosen regardless of the fact that this site has no line of sight to the other Roman forts. The addition of two relays in the form of fortlets proves that the line of sight was important for Wall builders, since with these fortlets, intervisibility with other parts of the frontier was possible. Wilderness Plantation and neighbouring minor enclosures are positioned on the only spot on the line of the Wall from which they could serve as a relay between Balmuildy and the eastern part of the frontier. While Wilderness East lies in the line of sight of Bar Hill and Kirkintilloch, Wilderness West is intervisible with Balmuildy itself while the fortlet Wilderness Plantation itself stands in the middle (**Pl. 1/8**).

None, so far presented, says that there was some signalling system working on the Antonine frontier in Scotland (!). The aim of the study was to examine in the artificial environment whether that was even possible. It seems that it was. Sites were in the vast majority positioned in places with a good line of sight to their neighbours and when they were not, relays did usually exist. It is questionable whether any kind of signal communication system could have existed – trees and bushes could obstruct the line of sight in some cases, especially when the intervisibility values calculated by Viewshed analysis are classified as "borderline" by the offB mark in the Appendix. The efficiency of signals transferred over a distance exceeding 5 km is also questionable not only because of the weather (fogs and mists effectively disrupt intervisibility) but also because of the absence of any kind of optical devices like binoculars for Roman soldiers. The conclusion therefore is that according to the calculations of the Viewshed analysis the signalling along the Roman frontier in Scotland was possible thanks to the good positioning of forts and their relays in the form of fortlets.

Apart from purely military reasons (blocking/controlling movement through the countryside) for the positioning of the forts on their actual spots, also the other reasons for the deployment of permanent garrisons and outposts could influence Roman builders and planners during frontier construction. One of them could be a necessity to see what was happening in the frontier area around the mural barrier itself – the Antonine Wall – from their permanent bases. Primary forts with fortlets and Camelon fort already provided good coverage of the frontier region in the already mentioned 6 km perimeter from the line of the Wall to the north (**Fig. 17**). When the secondary forts were added, the sightline to all regions was frequently doubled. That may seem to be superfluous but it is generally better for the day-to-day practice of controlling the landscape (**Fig. 18**). The best spots for observation of what was happening in the frontier region were Mumrills (**Fig. 11**), Bar Hill (**Fig. 1**) and Castlehill forts (**Fig. 5**) (see Appendix – the area observed in a 10 km perimeter).

The observation of what was happening in the frontier area was probably one of the reasons for the positioning of the seaside forts and fortlets plus Carriden and Old Kilpatrick in the locations where they were built. These military installations do not seem to be in any kind of visual contact with each other but the results of Viewshed analysis show that together they covered by line of sight the coastline of the non-Roman part of present-day Scotland very well, almost without duplicities (**Pl. 1/4**). One more fortlet between two known seaside fortlets (ideally on Dunrod Hill or more westward) could have improved the overall line of sight to the coastline area, but the existence of any such fortlet is questionable. Not only because of a lack of any archaeological evidence, but also because on the line of the most convenient and direct path (obtained via Cost path analysis) traces of a Roman road have already been documented.

A cost path analysis can be a useful addition to the Viewshed results. The unfavourable positioning of the Balmuildy primary fort that ignored the intervisibility with other Roman sites in the vicinity was probably chosen because of the good blocking function of that par-

ticular spot. A similar conclusion can be made about the fort at Bearsden, which could also serve as a good blocking point for north-south traffic (also in Graafstaal *et al.* 2015, 63). Despite standing in an area that is not visible from other Roman military installations, it lies on the best spot to block the free movement from native sites north of the Antonine Wall to the valley of the Clyde.

The presented paper tried to point out some qualities that should have had a permanent installation on a Roman frontier. It appears that one of the prerequisites for the layout of the Antonine Wall was a good line of sight from permanent military installations to the landscape and especially to locations of the other Roman military installations. The results of the Cost path analysis on the other hand clearly show that visibility and intervisibility was not the only prerequisite for choosing an ideal spot for a permanent military installation. Still, the conditions for the existence of a visual signal chain on the Antonine Wall were met and that sheds a new light on the initial question of this paper: How did frontiers actually work?

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APPENDIX

The sites in the left column of the table (**Tab. 1**) are sorted in the east-west direction and the numbers refer to the individual sites on figures and plates. The table is an attempt to visualize graphically the intervisibility results of the Viewshed analysis. The listed sites are those that could be seen from the fort/fortlet in the left column. When offB is in the bracket, the surface on which the mentioned fort/fortlet stood was not visible from the chosen spot but the position of the potential observer at the height of 5 m above the ground was still visible.

	Primary Forts	Secondary Forts	Seaside Forts	Forts north of the Antonine Wall	Fortlets	Seaside Fortlets	Area observed in 10 km perimeter (in sq km)
Primary Forts							
1 Carriden	-	-	-	-	-	-	76
2 Mumrills	-	Inveravon, Falkirk (offB)	-	Camelon (offB)	Kinneil, Watling Lodge (offB)	-	112
3 Castlecary	-	Rough Castle (offB)	-	-	Seabegs Wood, Garnhall (offB)	-	30
4 Bar Hill	Auchendavy	Rough Castle (offB), Westerwood, Croy Hill (offB), Kirkintilloch (offB), Castlehill (offB)	-	-	Croy Hill (offB), Glasgow Bridge, Wilderness Platation (offB), Summerston (offB)	-	213
5 Auchendavy	Bar Hill	Kirkintilloch (offB)	-	-	Summerston (offB) Castlehill	-	57
6 Balmuildy	-	Castlehill	-	-	Wilderness Plantation (offB), Summerston (offB)	-	20
7 Old Kilpatrick	-	-	Bishopton	-	-	Lurg Moor	27
Secondary Forts							
8 Inveravon	Mumrills	Falikrk (offB)	-	Camelon (offB)	Watling Lodge (offB)	-	77
9 Falkirk	Mumrills (offB)	Inveravon	-	Camelon (offB)	Kinneil, Watling Lodge (offB)	-	95
10 Rough Castle	Castlecary (offB), Bar Hill	Westerwood (offB), Croy Hill (offB)	-	Camelon	Seabegs Wood (offB), Croy Hill (offB), Garnhall (offB)	-	82
11 Westerwood	Bar Hill	Rough Castle (offB), Croy Hill (offB)	-	-	Easter Dullatur	-	54
12 Croy Hill	Bar Hill	Westerwood	-	-	Easter Dullatur, Croy Hill (offB)	-	91
13 Kirkintilloch	Bar Hill, Auchendavy	Castlehill	-	-	Glasgow Bridge, Wilderness Plantation (offB)	-	65
14 Cadder	-	Castlehill	-	-	-	-	37
15 Bearsden	-	-	-	-	-	-	6
16 Castlehill	Bar Hill, Auchendavy, Balmuildy	Kirkintilloch, Cadder, Duntocher (offB)	Bishopton	-	Glasgow Bridge, Wilderness Plantation, Cleddans	Lurg Moor	184
17 Duntocher	-	Castlehill (offB)	Bishopton	-	Cleddans	Lurg Moor	126
Seaside Forts							
18 Cramond	-	-	-	-	-	-	91
19 Bishopton	Old Kilpatrick	Duntocher, Castlehill	-	-	-	-	119

	Primary Forts	Secondary Forts	Seaside Forts	Forts north of the Antonine Wall	Fortlets	Seaside Fortlets	Area observed in 10 km perimeter (in sq km)
Forts north of the Antonine Wall							
20 Bertha	-	-	-	-	-	-	30
21 Strageath		-	-	-	-	-	50
22 Ardoch	-	-	-	-	-	-	88
23 Camelon	Mumrills	Inveravon, Falkirk (offB), Rough Castle (offB)	-	-	Kinneil, Watling Lodge, Garnhall	-	78
Fortlets							
24 Kinneil	Mumrills	Falkirk (offB)	-	Camelon (offB)	Watling Lodge	-	97
25 Watling Lodge	Mumrills	Inveravon, Falkirk	-	Camelon	Kinneil	-	108
26 Seabegs Wood	Castlecary	Rough Castle (offB)	-	-	Garnhall	-	25
27 Garnhall	Castlecary (offB)	Rough Castle (offB)	-	Camelon (offB)	Seabegs Wood	-	45
28 Easter Dullatur	-	Westerwood, Croy Hill	-	-	Croy Hill	-	32
29 Croy Hill	Bar Hill	Croy Hill, Westerwood (offB)	-	-	Easter Dullatur	-	81
30 Glasgow Bridge	Bar Hill	Kirkintilloch, Castlehill	-	-	-	-	49
31 Wilderness Plantation	Bar Hill, Balmuildy (offB)	Kirkintilloch, Castlehill	-	-	-	Lurg Moor	56
32 Summerston	Bar Hill, Auchendavy (offB), Balmuildy	-	-	-	-	-	28
33 Cleddans	-	Castlehill, Duntocher (offB)	-	-	-	Lurg Moor	67
Seaside Fortlets							
34 Lurg Moor	Old Kilpatrick	Castlehill, Duntocher	-	-	Wilderness Plantation (offB), Cleddans	-	114
35 Outerwards	-	-	-	-	-	-	51
Other possible fortlets: Cawder House (36), Boclair (37), Manse Burn (38), Hillside Hill (39), Dunrod Hill (40)							

Tab. 1: The sites intervisibility based on the results of the Viewshed analysis.

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Michal Dyčka
Institute of Classical Archaeology
Faculty of Arts, Charles University in Prague
Celetná 20, CZ-11000 Prague 1
dyckamichal@centrum.cz