Exploring the Antonine Wall with terrestrial remote sensing

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Chapter 1

1.1 The development of archaeological understanding of the Antonine Wall

The Antonine Wall is Scotland's largest ancient monument and, since 2008, a UNESCO World Heritage Site (WHS) (Figure 1.1). Its remains have been visited and recorded since the 16th century, antiquarian interest continuing intermittently thereafter until the mid-19th century (below). More systematic examination by excavation did not begin until the very end of that century and continues to this day, though most of it now in the form of relatively small-scale rescue work in advance of development.

Modern research interest in the Wall began with the work of the Glasgow Archaeological Society who undertook a sustained programme of excavation and survey of the linear barrier in the early 1890s, their published results accompanied by a brief overview of previous ancient and antiquarian accounts (GAS 1899). The first overall synthesis of knowledge about the Wall – *The Roman Wall in Scotland* - was published by George (later Sir George) Macdonald in 1911. It included not just a descriptive account of the visible remains and the results of the early excavations at fort sites such as Castlecary, Rough Castle and Bar Hill, but a consideration of the literary sources, historical context and associated inscriptions, with a particular focus on the distance slabs, a unique feature of the Antonine Wall that record the lengths of Wall built by particular legions.[1] The volume was fully revised and expanded in 1934 to include archaeological investigations which had taken place in the intervening years, many of them Macdonald's own. Indeed, these years had seen a considerable expansion of knowledge with, as Macdonald himself notes in the preface (1934: vii), more than a doubling of the number of forts that had been subject to excavation, including Old Kilpatrick, Balmuildy, Cadder, Croy Hill, Westerwood and Mumrills. Of particular note was the inclusion of a series of pull-out extracts from the Ordnance Survey six-inch to the mile maps on which the line of the Wall and its associated features was traced in red.

The next landmark was the publication in 1960 of *The Antonine Wall: a handbook to the Roman Wall* by Anne Robertson, which provided a site-by-site account of the remains with a fairly lengthy general introduction to the monument and its context. This went through three editions until 1979. Then came something of a sea change with the appearance in 1983, followed by a slightly revised paperback edition in 1986, of *Rome's North-West Frontier: the Antonine Wall* by William Hanson and Gordon Maxwell. This set out not 'to provide a guide to the Wall as it survives today, nor to give a detailed description of its physical remains as understood from archaeological excavation', even though elements of the latter inevitably were included, but was 'concerned to locate the frontier within its historical background, to try to explain why and how it was built, how it functioned, and to assess what effects it had upon the later history and development of the northern frontier' (1986: xi). This book was able to take into account not only important large-scale excavations undertaken in the 1970s at two forts (Bearsden and Croy Hill), but smaller scale excavation at several new fortlets (Cleddans, Wilderness Plantation, Croy Hill, Seabegs Wood and Kinneil), the identification and examination of a new type of site, the minor enclosure, and a review of all the known construction camps. As a result, it was rapidly to become the standard work on the subject and remains the most comprehensive and detailed modern account of the Wall.

Lawrence Keppie, who had himself undertaken extensive fieldwork on the Wall, finding new fortlets and paying particular attention to the evidence for variations in its construction (e.g. Keppie 1974; Keppie and Walker 1981), took over editing Robertson's handbook in 1990. He maintained the same general format (and, indeed, attributed authorship) while expanding the content, updating the illustrations and slightly amending the title. He produced two more editions, the most recent in 2015 (Robertson 2015). Meanwhile, stimulated by the proposed nomination of the Wall as a World Heritage Site (below), David Breeze produced a more popular synthetic overview, setting out 'not just to describe the Wall, but to place it in its British and Roman imperial setting and consider its importance and significance' (2006: xii).

As well as continuing to edit the handbook, Lawrence Keppie had undertaken a major review of the epigraphic and sculptural evidence, including a detailed analysis of

[1] This long-standing standard term for this group of inscriptions has recently been challenged on the grounds that it 'conjures an outmoded and inappropriate notion of this body of material as bland, uninspiring, functional blocks of stone devoid of any character or intrinsic cultural significance' (Campbell 2020: 176). The Shorter Oxford English Dictionary defines slab as 'a flat, broad and comparatively thick piece or mass of anything solid' and it is commonly used to describe other building inscriptions or tombstones that fit such a definition. Thus, the term distance slab is simply a conveniently precise and descriptively accurate term that need not carry any of the ascribed implications and so does not require to be changed.

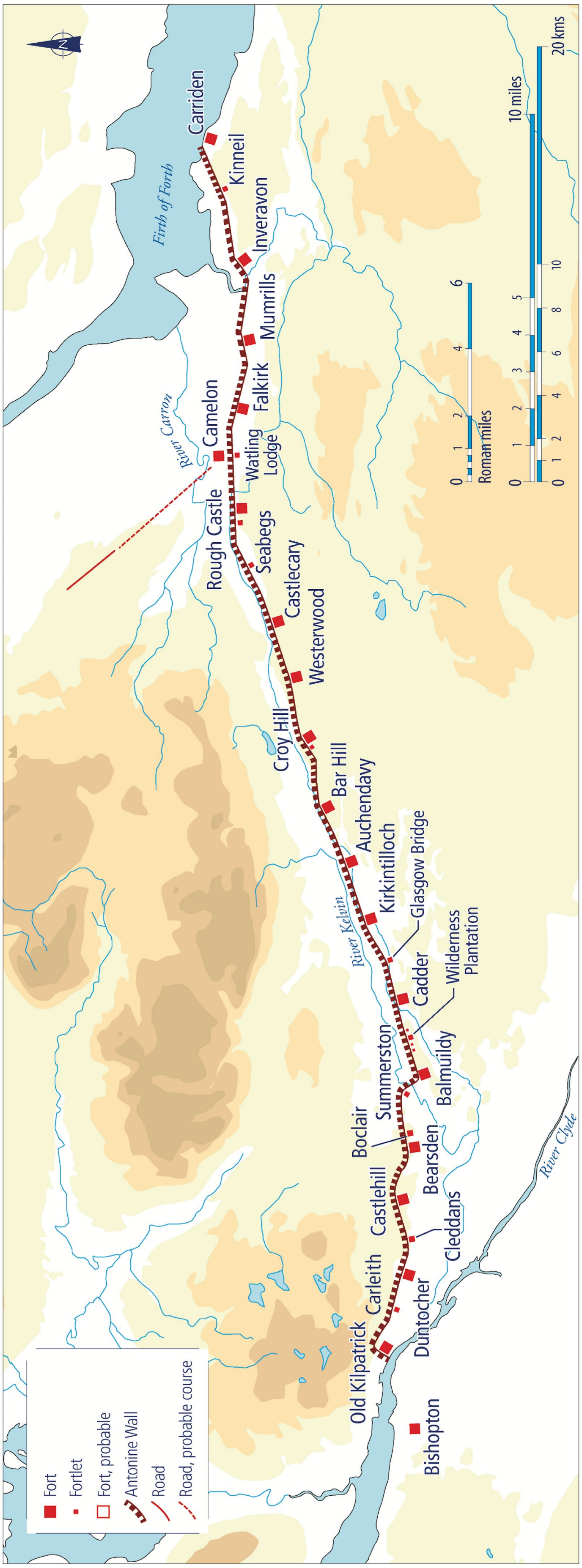

Figure 1.1. Map of the Antonine Wall as completed (© D.J. Breeze).

the distance slabs (1998: 49-58 and 72-130). It is fitting, therefore, that the most recent synthesis, a collection of papers by some 30 specialists summarizing the most up-to-date work on the Wall, should be dedicated to him (Breeze and Hanson 2020).

Finally, the detailed account of all the excavations and small-scale interventions undertaken by Geoff Bailey and his team of volunteers in Falkirk District appeared in 2021. This substantive volume includes reports on work in or around the forts at Carriden, Mumrills, Falkirk and Castlecary, the fortlet at Kinneil and stretches of the Wall between these sites, as well as more general discussion of selected topics.

1.2 Other non-invasive exploration of the Antonine Wall

This section briefly reviews how the Antonine Wall has been mapped and recorded over the centuries on the basis of surface observations. It also addresses the role that this data plays in enhancing our understanding of the monument, whether obtained from simple mapping of visible remains, from aerial reconnaissance, fieldwalking or from LiDAR survey.

1.2.1 Mapping and recording

The history of antiquarian interest and early mapping of the Antonine Wall has been well researched for the period up to the end of the 19th century (Keppie 2011; 2012). As early as the 13th century, the Antonine Wall featured on a map of Britain appearing in a world history created by an English monk, Matthew Paris. To Timothy Pont, however, goes the credit of listing forts he found in the course of his own fieldwork in the later 16th century, though the route he depicts of the Wall is not always fully accurate. He is given credit by Sibbald for a detailed schematic sketch of the main features of the Wall and is regarded by Keppie as a pioneer in the fieldwork and observation of its surviving remains (2011: 99). More than a century later the antiquarian, Sir Robert Sibbald, though undertaking no fieldwork himself, drew on the combined information available to him to produce a map of the Wall published in his *Historical Inquiries* (1707), in which he also included a diagram of its constituent elements derived from Pont's work (Figure 1.2).

Over the course of the 18th century William Stukeley (1720), Alexander Gordon (1726) and in particular John

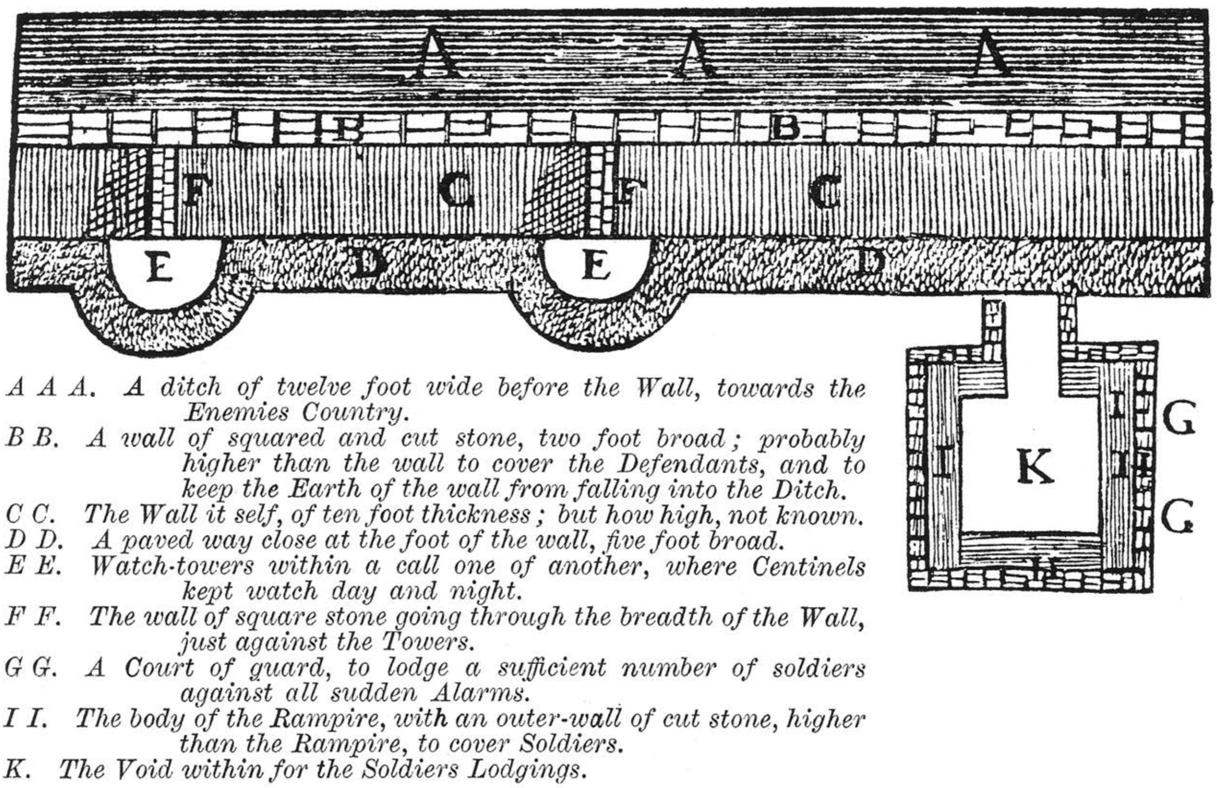

Figure 1.2. Schematic diagram of the features of the Antonine Wall produced by Sibbald, after Pont.

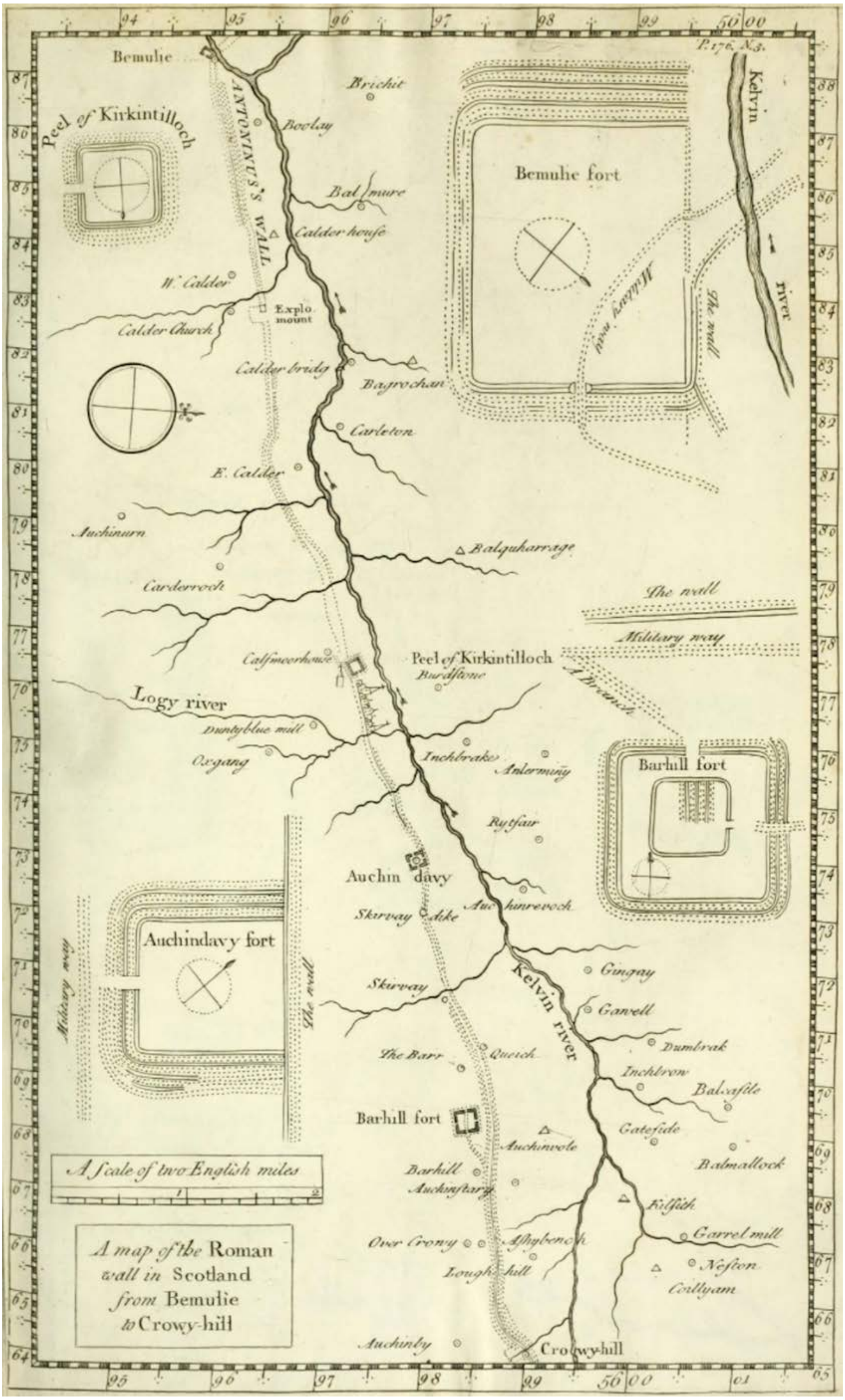

Figure 1.3. Horsley's map of the Antonine Wall between Balmuildy and Croy Hill.

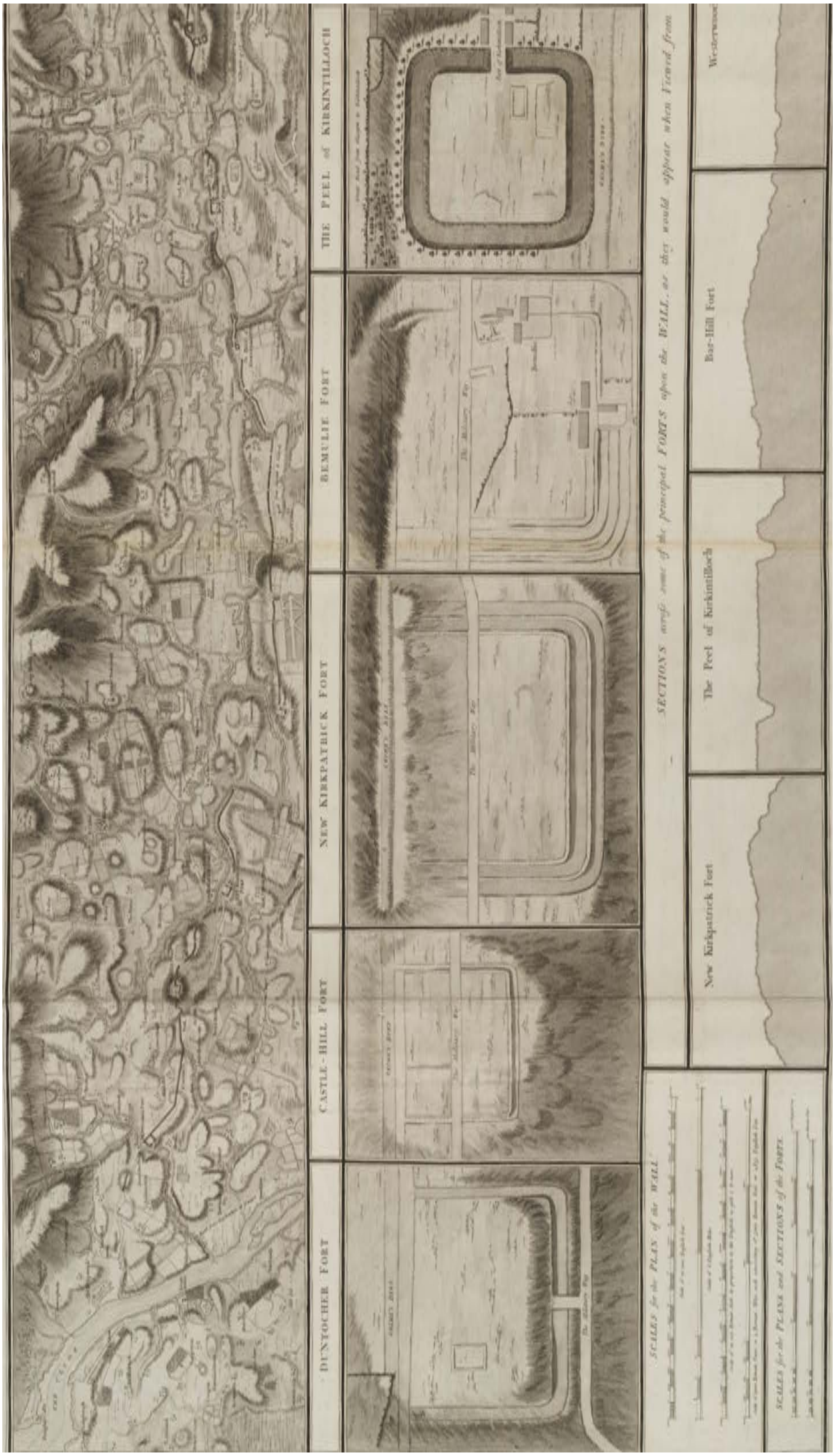

Figure 1.4. Extract from Roy's map of the Antonine Wall, showing the surviving course of the western end of the Wall and plans of the forts at Duntocher, Castlehill, Bearsden (New Kirkpatrick) and Balmuildy (Bemulie), along with the early medieval motte at Kirkintilloch (Roy 1793, Fig. 35).

Horsley (1732) produced increasingly sophisticated maps, as well as plans of individual forts and records of inscriptions, that accompanied their various accounts of the Wall (e.g. Figure 1.3). But it was General William Roy, charged with the major task of producing the Military Survey of Scotland in the aftermath of the Jacobite Rebellion (Roy 2007), who made the most significant contribution (Maxwell 1989b: 8-9: Keppie 2012: 91-92). The combination of a soldier's practical experience in managing military affairs, an understanding of the terrain, a keen interest in the Roman world and a knowledge of ancient military texts enabled him to map and record the Wall and other Roman sites in Scotland to a level of detail (at a scale of 1:36,000) and accuracy that was not to be surpassed for a century (Figure 1.4). The importance of his work, published posthumously in 1793 as his *Military Antiquities of the Romans in North Britain*, is widely recognised, and it continues to be consulted (see, for example, Chapter 2.5, below).

When the industrial revolution was already well underway in central Scotland in the early 19th century, the account of a five-day journey on foot along the Antonine Wall in September 1825 by an English clergyman and antiquarian, John Skinner, gives a snapshot view through his coloured sketches of the condition of the monument at that time. Skinner's account provides a systematic description of what he saw along the course of the Wall, the surface remains of forts, the Military Way and the presence of inscribed and sculptured stones (Keppie 2003). Skinner's observations make plain the survival of both the linear barrier and some of its fortifications at numerous places where now little is evident. Yet the effects on the monument's integrity of more intense agriculture, stone robbing and the construction of the Clyde-Forth Canal, which had opened in 1790, were already sadly apparent.

Such records were, however, more impressionistic than planimetrically accurate. It was not until the 1st edition of the Ordnance Survey's 6-inch and 25-inch maps, surveyed between 1854 and 1861, that we get a large-scale, metrically accurate topographic record of the Wall line (Figures 1.5, 2.2.2 and 5.4.10) (Jones and McKeague 2011: 147). While preservation of the linear barrier, usually represented only by its Ditch and perhaps the Upcast Mound beyond it, is consistently greater than is evident today, most of the fortifications along its line were already barely or no longer visible as earthworks. Indeed, further deterioration can be tracked through later editions of these maps, particularly where the Wall passed through expanding urban areas. For example, the line of the Wall Ditch was still visible on the 1st edition Ordnance Survey maps for most of its course from Old Kilpatrick to Balmuildy. There was also at least some indication of the ditches outlining the forts at Duntocher and Bearsden (then known as New Kilpatrick), though all trace of Old Kilpatrick and Balmuildy had already disappeared under building or agricultural development respectively. At the time of the resurvey in 1896, which broadly coincided with the first systematic archaeological fieldwork being undertaken along the Wall (GAS 1899), much of the Wall line was still visible in this sector, and the line of the ditches on the west side of the fort at Castlehill had also been recognised, but the fort at Bearsden had been almost completely built over. However, by the time of the 1914 map revision most of the line of the Wall Ditch between the Old Kilpatrick and Balmuildy had been either ploughed flat or built over, and nothing remained visible of either Bearsden or Castlehill forts. A similar pattern can be seen along much of the rest of the Wall, with variations in the chronology of destruction, leaving only pockets of good preservation by the mid-20th century. Indeed, it has been estimated that by 1973 no reasonably intelligible remains were visible on the ground for almost 80% of the linear barrier (Skinner 1973: 16-17 and Fig. 2).

As noted above, this systematic Ordnance Survey mapping provided the basis for Sir George Macdonald's detailed fieldwork and exploration of the Wall (1934). But that interaction was a reciprocal process (Linge 2004: 161; McKeague 2020: 433-34), which resulted also in the generation by the Ordnance Survey of a dedicated and large-scale map folio of the Wall based on information Macdonald provided (Ordnance Survey 1931). Interestingly, however, this information did not always sit well with their own earlier mapping, which they tended to choose to ignore in favour of Macdonald's line (Linge 2004: 162; Jones and McKeague 2011: 1417), though sometimes their deference was misguided (see Chapter 2.2, below). Nonetheless, some years later the Ordnance Survey felt sufficiently confident in their data to produce a dedicated map of the Antonine Wall which shows its entire line on a single sheet at a scale of 1:25,000 (1969).

As more information from excavations became available, however, the inconsistencies and inaccuracies evident at larger scales became increasingly problematic, exemplified by the difficulties of determining the line on the western side of Falkirk, requiring a more root-and-branch revision (Linge 2004: 162-63). Thus, shortly before the transfer of their responsibilities for archaeology to the Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS), now part of Historic Environment Scotland (HES), the Ordnance Survey undertook a re-survey of the whole length of the Wall taking into account all fieldwork and excavation data then available. This resulted in a folio of 122 maps at scales of 1:1250 and 1:2500 (1980), along with a separate Reference/Field Report Folio documenting both the sources of the information and

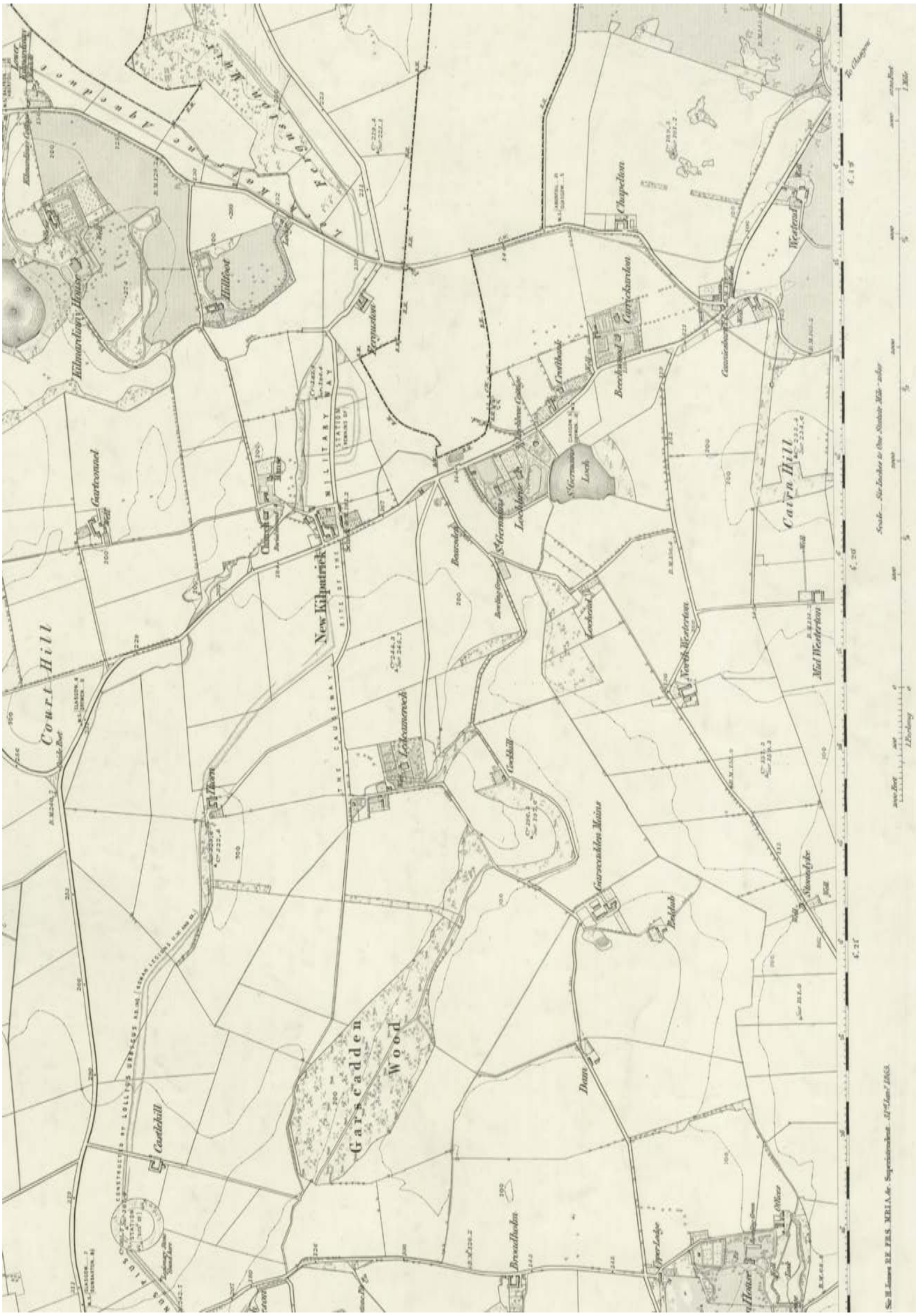

Figure 1.5. Extract from the 1st edition Ordnance Survey 6-inch map surveyed in 1861, showing the extant line of the Antonine Wall from Castlehill to Ferguston Muir (Reproduced with the permission of the National Library of Scotland. CC-BY (NLS)).

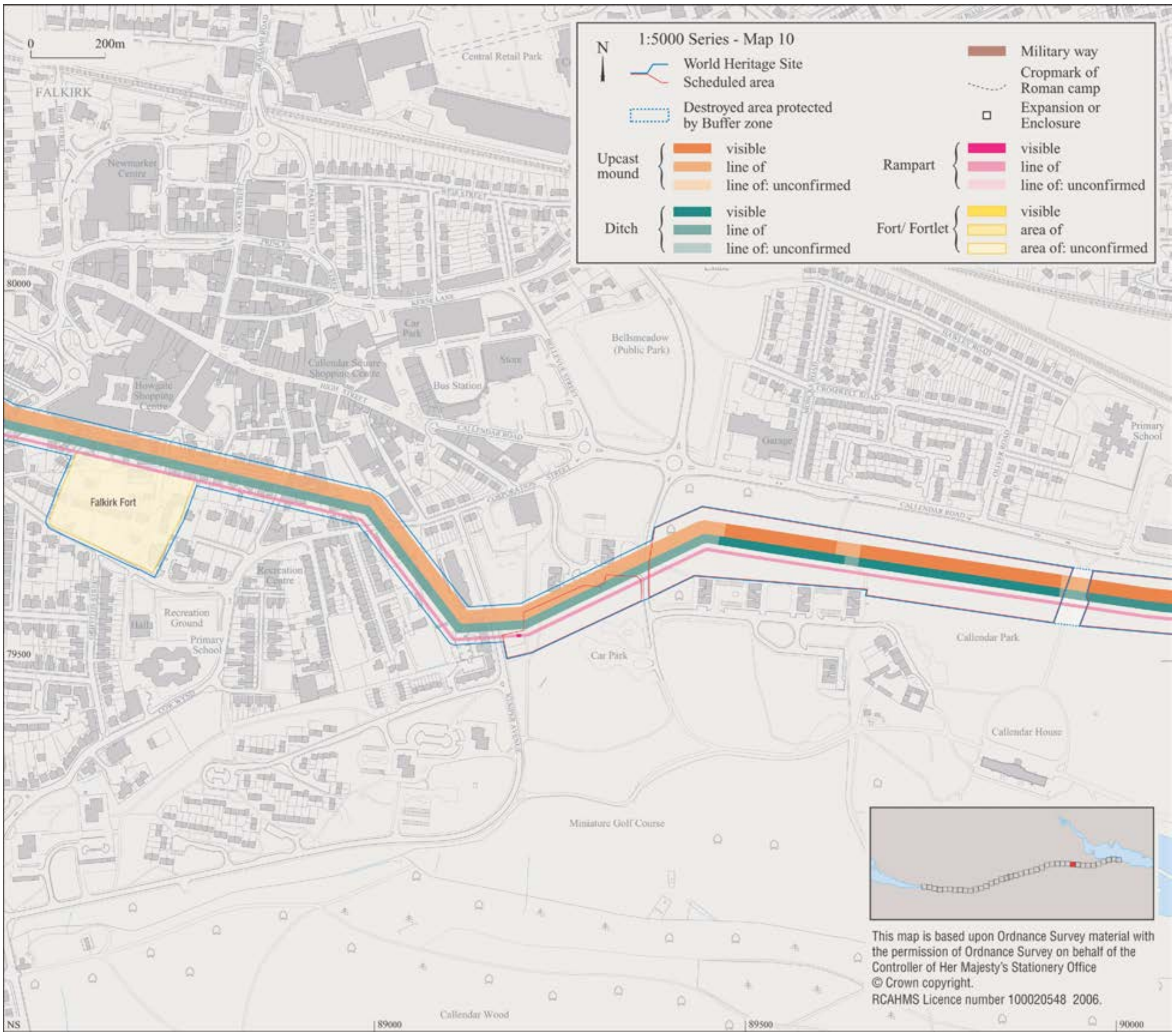

Figure 1.6. Sample map depicting the components of the Antonine Wall based on the World Heritage Site nomination documentation (after Historic Scotland 2007, vol. II, V-10-CS2 by courtesy of Historic Environment Scotland).

observations from their own fieldwork (Linge 2004: 162-66; McKeague 2020: 437-39). It is perhaps less surprising, therefore, that in the course of preparing this volume, we have encountered examples where excavators pursuing the line of the Wall, because its remains were no longer in evidence, have noted that the line recorded on large-scale Ordnance Survey maps was inaccurate. In cases where the line of the Ditch was actually visible in 1896, reliance on the 2nd edition Ordnance Survey mapping would have provided suitable correction (e.g. Chapters 2.8, 5.6 and 7.1).

There has been no further Ordnance Survey map revision to take into account the excavation and fieldwork which has taken place since 1980, and the archaeologists involved in that work seem to have been largely unaware of this important earlier resurvey data (Linge 2004: 166-67). However, as part of the preparations for the successful nomination of the Antonine Wall as an extension of the transnational *Frontiers of the Roman Empire World Heritage Site*, the data was reviewed again and a new set of 39 maps produced at a scale of 1:5000 incorporating detail from excavations and geophysical surveys undertaken up to that time, along with a comprehensive Global Navigation Satellite System (GNSS) survey of the monument conducted by Georgina Brown (Historic Scotland 2007; Jones and Brown 2007). In recognition of the variation in the level of detail available for different elements of the Wall, particularly the Upcast Mound, a somewhat stylised depiction of the various components was adopted (Figure 1.6) (Jones and McKeague 2011: 150-54; McKeague 2020: 440-41). This review also formed the basis for the publication of a revised map for use by the general public at a scale of 1:25000 (RCAHMS 2008).

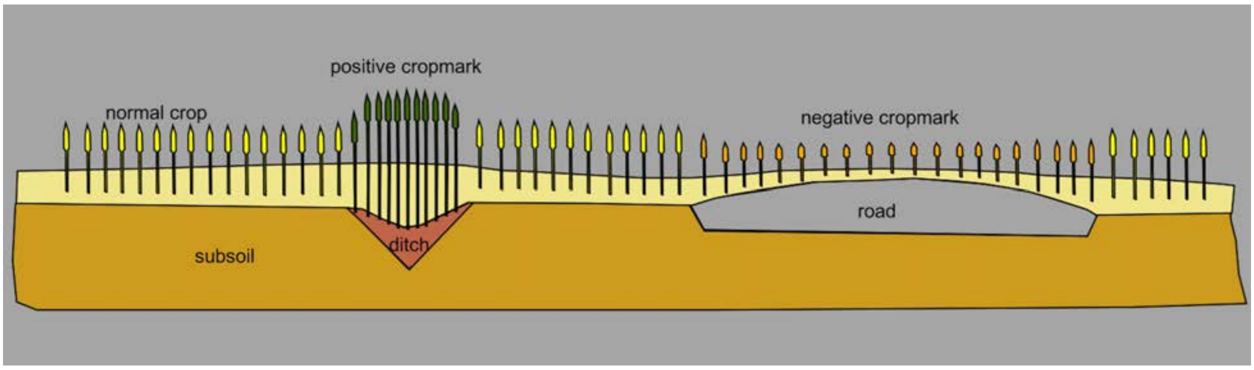

Figure 1.7. Diagram showing how cropmarks are produced.

Figure 1.8. Aerial photograph of part of the camp at Easter Cadder (left foreground) with the line of the Antonine Wall Ditch, Rampart (arrowed in white) and the Military Way (arrowed in black) beyond it to the right, all bisected by a modern pipeline. All are revealed as cropmarks, the Military Way primarily as a line of quarry pits. View from the east.

Figure 1.9. Aerial photograph of the double ditches of the fortlet at Wilderness Plantation revealed as cropmarks at the rear of the Wall. View from the south-west.

1.2.2 Aerial photography

Though O.G.S. Crawford had undertaken two pioneering flights in Scotland in the 1930s (1939), it was J.K.S. St Joseph, primarily under the auspices of the Cambridge University Committee for Aerial Photography established in 1949 (CUCAP), who developed and expanded the application of aerial reconnaissance so that it became one of the most important methods of archaeological survey in Britain. St Joseph had a particular interest in Roman military sites and from the mid-1940s undertook reconnaissance in Scotland almost every summer until his retirement in 1980 (e.g. St Joseph 1949; 1976). It was not until 1976, however, that RCAHMS established its own systematic programme of reconnaissance under G.S Maxwell, who also had a strong interest in Roman archaeology. This development was accompanied by increased activity by local flyers, including the first named author.

Figure 1.10. Google Earth image of cropmarks defining the south-east corner of the fort and eastern annexe at Mumrills in 2013 (© 2019 Maxar Technologies).

Archaeological sites can be revealed from the air in one of three main ways (Wilson 2000: 38–80). Where they are extant, even if so little survives that they are not readily appreciated from the ground, they may be revealed from the air by virtue of the pattern created by the shadows cast in low sunlight, an effect which can be enhanced by a light covering of snow. These types of photograph are used primarily for illustrative purposes in relation to well-preserved parts of the Wall (e.g. Robertson 2015: Figs 43, 53 and front cover), though they can also provide instructive information about them (e.g. Maxwell 1989a: 177 and Figs 14.9-14.11).

Since, as a result of the destructive impact of the plough (above), most of the Wall is now largely invisible above ground even where it is not built over, the most important contribution of aerial survey comes from the identification of cropmarks (Figure 1.7). Once growing plants have exhausted the water stored in their rooting zone, they begin to suffer moisture stress and to wilt. Plants growing over buried stone foundations will have a more restricted rooting zone and exhibit signs of moisture stress before other plants in the same field, so that their growth will be less luxuriant and they will ripen more quickly generating negative cropmarks. The opposite occurs where plants are growing over buried pits or ditches, producing positive cropmarks – that is, areas of relatively enhanced crop growth. However, the combination of factors which best suit cropmark production – dry weather patterns, well-draining soil types and fields of cereal crops – apply relatively infrequently to much of the line of the Antonine Wall, particularly towards its western end (Maxwell 1989a: 174).

Nonetheless, all 21 of the temporary camps associated with the construction of the Wall are cropmark discoveries (Hanson and Maxwell 1986: 117-21; Jones 2005) (e.g. Figure 1.8), as are the only three minor enclosures currently known attached to the rear of the linear barrier (Hanson and Maxwell 1983). However, only three of the known fortlets, at Summerston, Wilderness Plantation (Figure 1.9) and Glasgow Bridge (Figure 3.4.3), and one fort at Carriden were actually discovered from the air (Maxwell and Hanson 2020: 193-94; Wilkes 1974: 51; RCAHMS 1978: 134 and plate 13a; St Joseph 1949: 167-70 and pl. XXXIII). A second fort discovery, that of Mumrills, may be at least in part attributed to the recognition of cropmarks, though in that case from the ground rather than from the air (see Chapter 6.5, below). In addition, the recording of cropmarks has further enhanced our understanding of some other forts, such as Castlehill and Auchendavy (Keppie 1980: 82-83; Keppie and Walker 1985: 29-32 and pl. I), and has helped confirm the line of the Wall and Military Way in various locations where all surface traces have been removed by the plough (e.g. Figure 1.8).

The primary source of archaeological aerial photography for the area is the National Record of the Historic Environment (NRHE) maintained by HES in Edinburgh. This holds not only the oblique photographs from its own reconnaissance, but copies of at least a representative selection of photography from other sources. Increasingly, such material is being made available directly online through the online catalogue to Scotland's archaeology, buildings, industrial and maritime heritage provided by the NRHE, currently branded as Canmore.[2] With the advent of the website Google Earth the availability of satellite imagery has further enhanced access to aerial images, though this coverage, which also includes a substantial proportion of vertical aerial photography, has only occasionally been acquired in conditions most suitable for the recognition of archaeological sites (e.g. Figure 1.10).

1.2.3 Fieldwalking

Walking over recently ploughed fields to recover artefacts, mainly pottery, is a useful way of discovering potential new sites. Though this methodology has been applied relatively infrequently along the Antonine Wall, it has been responsible for the primary discovery of the fortlets at Seabegs Wood and Kinneil, and the recovery of an important altar from outside the fort at Westerwood (Keppie and Walker 1981: 143-54; Walker 2020). Fieldwalking supported by metal detecting, with the careful plotting of the finds recovered, can also provide additional information about known sites. Work by the Falkirk Local History Society in conjunction with the Edinburgh Archaeological Society at Carriden provided support for the identification of the military enclosure recorded on aerial photographs as an annexe on the basis of the more limited recovery of Roman finds from the relevant field compared to their fieldwalking across the east side of the fort at Mumrills (Bailey 2021: 205-09 and 238-50). Comparison of the variable concentration of different types of material at the latter has also helped to suggest areas that may be linked to specific activities or buildings within the fort.

1.2.4 LiDAR

During the last twenty years, Airborne Laser Scanning (ALS), commonly known as Airborne LiDAR (Light Detection and Ranging Survey), has seen increasing application in British archaeology (e.g. Figures 2.1.2; 2.3.8; 2.5.4). This technique involves directing a pulsed laser beam at the ground and recording the reflections that bounce back (Crutchley and Crow 2018: 1-12 and 56-61) (Figure 1.11). Measuring the time differential for each pulse provides a means of recording very slight variations in surface elevation even in wooded areas, as a portion of the beam can still penetrate the tree canopy and reach the ground surface, although close-planted conifers can prove impenetrable. Using a mathematical algorithm, the reflections from the surface and the canopy can be distinguished, allowing the surface to be mapped. Digital terrain models can then be produced from this data, allowing mapping and identification of archaeological features even if they are only barely visible above ground. The potential visibility of such ephemeral archaeological remains is related to the resolution of the data, which depends on the number of points recorded per square metre. This in turn depends partly on the flying height of the aircraft housing the scanner, but also on the pulse rate of the scanner. In broad terms, the utility of LiDAR data for recording archaeological features improves with greater ground point densities, with concomitant increases in the detail that may be observed. LiDAR data can be visualised in many different ways to maximise the visibility of archaeological remains. Single and multi-direction hillshade visualisations are commonly used as they are broadly similar to the type of image obtained from low-light aerial photographs and are relatively intuitively interpreted. However, more complex visualisations may also be utilised, such as principal component analysis of multiple hillshades, or sky view factor (Kokalj and Hesse 2017).

As part of the Scottish Ten Project, in 2010 HES commissioned the acquisition of LiDAR data for the whole Antonine Wall World Heritage Site and its buffer zone. This data was captured at a density of 6-7 points per square metre and used to generate a Digital Elevation Model (DEM) at 0.5m resolution (Wilson *et al.* 2013). This data has recently been analysed by the third named author and formed the basis of his PhD (Hannon 2018). The major contributions of this work have been the recognition that the real length of the Wall, as measured on the ground taking into account changes in elevation, is slightly longer than previously appreciated (Hannon *et al.* 2017: 453-55) and that the fortlets known along the Wall (below) do seem to fit a consistent pattern of spacing at one Roman mile apart (Hannon *et al.* 2020: 69-73). Unfortunately, the data collection methodology and point density were not optimal for

[2] At the time of writing we understand that the Canmore web resource is in the process of rebranding to become 'Trove', but that the relevant reference numbers will be maintained and HES will ensure that links to Canmore numbers are maintained.

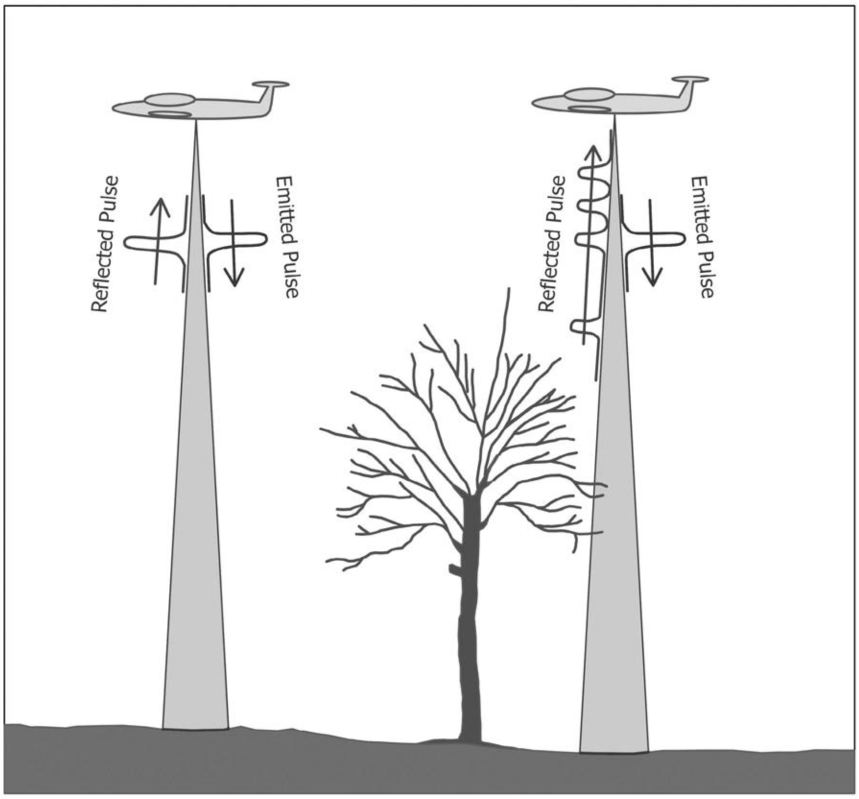

Figure 1.11. LiDAR explanation diagram.

the identification of subtle archaeological features. The project concluded that a point density sufficient to allow the generation of a 0.25m resolution DEM was preferable (Hannon 2018: 435). While the project was not able to facilitate the discovery of any convincing new sites of Roman date, it did provide additional information about the field system to the south of the fort at Rough Castle (Hannon 2018: 275-78). In addition, in 2017 the Environmental Agency released a range of LiDAR datasets including one at 1m resolution which covered most of the Central Belt (Edina 2017). These two sets of LiDAR coverage provide extremely useful sources of background and comparative data against which to view both aerial photographic and geophysical surveys (e.g. Chapters 2.5; 4.4; and 5.3 below). These datasets have now been supplemented by Scottish Public Sector LiDAR, including data initially captured by Fugro during 2020 and 2021 for the Scottish Power Energy Network to monitor their overhead power cable network (https://remotesensingdata.gov.scot/data#/map).

1.3 The context of the geophysical surveys

Historic Scotland's application to UNESCO for World Heritage status for the Antonine Wall in 2007 required up-to-date mapping of the monument. This task was accomplished by RCAHMS on behalf of Historic Scotland (now HES) (Historic Scotland 2007). Historic Scotland widened RCAHMS' remit to include the creation of a GIS to incorporate all archaeological work which had taken place from 1980 (or earlier where possible); in this way GIS would form an important tool for the proper protection and management of the monument. Also needed was the definition of a buffer zone, to be based 'on visibility to and from the proposed WHS, and analysis of the land-use setting, including urbanised areas' (Breeze 2011: 90).

Concurrently, and feeding into this exercise, Historic Scotland was managing a European Union project within the Culture 2000 programme, *The Frontiers of the Roman Empire* project (Breeze and Jilek 2008a). One of its aims was to draw on non-invasive methods, particularly geophysical survey, to resolve questions both about the courses of the Antonine Wall and the Military Way where there was uncertainty, and about the environs of forts. Traditionally the latter have not received much attention, particularly in relation to the potential locations of civilian settlement. The project provided the necessary impetus for a major programme of fieldwork, the time being right to adopt geophysical survey since it had made major contributions towards understanding the military and civil components of the Roman presence on Hadrian's Wall and its western coastal extension (Biggins and Taylor 2004a; 2004b; 2007).

The work was divided between GSB Prospection, a company that has considerable experience of geophysical survey at archaeological sites in Britain (Gaffney and Gater 2010), and the Archaeology Department at Glasgow University, which has been active in the field for several years (Jones and Sharpe 2006). The former focused on locating sections of the Ditch, Rampart and Military Way, involving both targeted transect-type and large area surveys; the latter undertook more extensive surveys, including the environs of forts, to investigate the possible locations of extra-mural settlement. Much of the fieldwork was carried out between 2007 and 2010. Stephens *et al.* (2008) gave an outline of the early results that, not unexpectedly, led to further effort at some sites and encouraged new work at others (Jones and Leslie 2015: 318-323).

In 2008 the Antonine Wall became part of UNESCO's Frontiers of the Roman Empire WHS, a transnational entity that includes the two Walls of northern Britain together with the extant German *limes*. In justifying this status, UNESCO drew attention to their high cultural value as outstanding examples of, *inter alia*, Roman military architecture and building techniques (https://whc.unesco.org/en/list/430/). Crucially, this status requires their state guardians to have suitable protection and management measures in place and to encourage new research. These measures are outlined in HES's management plan 'mapping out a five-year plan for the management and conservation for the Antonine Wall' (HES 2016) which is currently under review. As regards new knowledge about the Antonine Wall, research priorities were identified within the Scottish Archaeological Research Forum's (ScARF) Roman panel report (ScARF 2012: 3.5) and more directly by the recent Antonine Wall Research Agenda produced by HES (ScARF 2023). Of crucial relevance here is the message from both panels that integrated approaches to military landscapes should be encouraged, bringing in, where appropriate, topographical and aerial survey, LIDAR, geophysics, the use of stray and metal-detected finds, as well as fieldwalking and, ultimately, excavation. The obligation to open the Antonine Wall to a wider public is well in place offering a range of resources whether digital, in the museum or on site (https://www.antoninewall.org/).

The third main contribution to this volume concerns an ongoing programme of survey being undertaken at HES by the third named author. This programme forms part of a 5-year, Historic Scotland Foundation-funded project aimed at developing a geophysical survey capacity embedded within HES' Archaeological Survey team. Work within the World Heritage site not only addresses a range of management and research questions, but also provides ideal training opportunities for HES team members. Complementing the surveys by GSB and Glasgow University (GU), this work takes a larger landscape approach, appropriately employing the newer generation of gradiometer instrument with the multi-sensor system loaded on a cart in order better to facilitate the examination of large areas (Table 1.2).

Finally, surveys undertaken by other operators, such as the Centre for Field Archaeology (CFA), GUARD and GUARD Archaeology have been included, so that, as far as possible, all the surveys known to have been carried out along or near the Wall to date have been included (Table 1.1).

1.4 Geophysical methodology

Table 1.2 lists the instruments employed by the various operators, with associated technical detail on data gathering and processing.

Two techniques, often regarded as the workhorses of geophysical survey, have been to the fore on the Antonine Wall, as well as in the corresponding work on Hadrian's Wall (e.g. Biggins and Taylor 1999): magnetometry, in the form of the fluxgate gradiometer, and earth resistance (Figures 1.12 and 1.13). Gaffney and Gater (2010: 26-40 and 61-67) and Schmidt *et al.* (2015: 59-74) introduce the techniques and illustrate the relevant instruments. The gradiometer has usually been recognised as the technique of choice because of the speed with which it generates data and its ability to detect most structures and features associated with the Roman military presence, although it is disturbed by ferrous objects within the survey area and by the presence of igneous bedrocks. Electrical resistance survey, which complements gradiometry, is best suited to the detection of stone buildings and metalled roads, as well as ditches of the kind that surround fortifications. But the technique may be prone to yielding less information and at lower resolution than gradiometry for several reasons, most notably its sensitivity to localised soil conditions such as variable moisture content.

As the relevant instrument passes over a buried feature, the measured readings change with respect to the archaeologically sterile surrounding soil giving rise to an anomaly: a gradiometer anomaly appears as a magnetic gradient and is characterised by its strength and polarity (for example a strong positive anomaly), while a resistance anomaly manifests itself according to a scale from low to high resistance. Using specialised software (see Table 1.2), the anomalies are visualised most frequently as grey-scale displays of a kind that appear throughout Chapters 2 to 7. Accompanying the image is a palette defining what normally represents the range from high (black) through to low (white)

Table 1.1. All known geophysical surveys on the Antonine Wall

Site	Targets	Operator
Old Kilpatrick	Rampart, Ditch & Military Way	HES
Carleith	Fortlet, Rampart & Ditch	HES
Duntocher	Fort, fortlet, annexe, Rampart & Ditch, bathhouse	GU/HES
Cleddans	Rampart & Military Way	GSB
Castlehill	Fort, fortlet, Rampart & Ditch	GU
Bearsden	Fort ditches	GUARD
Boclair	Ditch	GUARD Archaeology
Summerston to Balmuildy Bridge	Ditch, Rampart, Upcast Mound, Military Way, fortlet & temporary camp	GSB
Balmuildy	Fort, annexe, Rampart, Ditch & environs	GU
Wilderness Plantation	Ditch, Rampart & Military Way	GSB
Cawder	Ditch, Rampart & Military Way	GSB/GU
Glasgow Bridge to Westermains	Ditch, Rampart, Military Way, fortlet & possible minor structures	GSB
Kirkintilloch, Peel Park	Fort	GUARD/HES
Auchendavy	Fort, Rampart, Ditch & environs	GU
Shirva	Ditch, Rampart, Military Way & potential fortlet	GSB/CFA/Strang and Walker/HES
Bar Hill	Rampart, Military Way, possible fortlet, temporary camp & environs	GU/Strang and Walker
Girnal Hill/Nethercroy	Ditch, Military Way and possible fortlet	GSB/Bradford
Croy Hill	Fort, fortlet, camp, extra-mural settlement, Military Way and bypass road	GU
Westerwood	Fort, extra-mural settlement, & Military Way	GU
Tollpark	Rampart and Military Way	GU
Garnhall	Rampart, Military Way, temporary camp and possible watchtower	Woolliscroft
Castlecary	Fort, annexe & environs	GU/GSB
Seabegs	Rampart, Berm & Military Way	GSB/HES
Milnquarter	Ditch, Rampart & Military Way	HES
Elf Hill, Bonnyside	Rampart & possible fortlet	GU
Bonnyside to Rough Castle	Rampart, Berm, Military Way, expansion & fortlet	HES
Rough Castle	Fort, annexe & field system	GSB/HES
Callendar Park	Rampart, Military Way & potential fortlet	GU
Mumrills	Fort, annexe, Rampart, Ditch, Military Way & environs	GSB
Inveravon	Fort, Ditch, Rampart & Military Way	GSB, Clark
Kinneil	Ditch, Rampart, fortlet, Military Way & environs	CFA, GSB, Hannon, HES
Kinglass Park	Rampart, Military Way & temporary camp	GSB/Edinburgh Archaeological field Society
Muirhouses	Temporary camp and putative Wall line	GU
Kinningars Park & Carriden western environs	Eastern terminus of the Wall	GU
Carriden	Fort, annexes & environs	GU

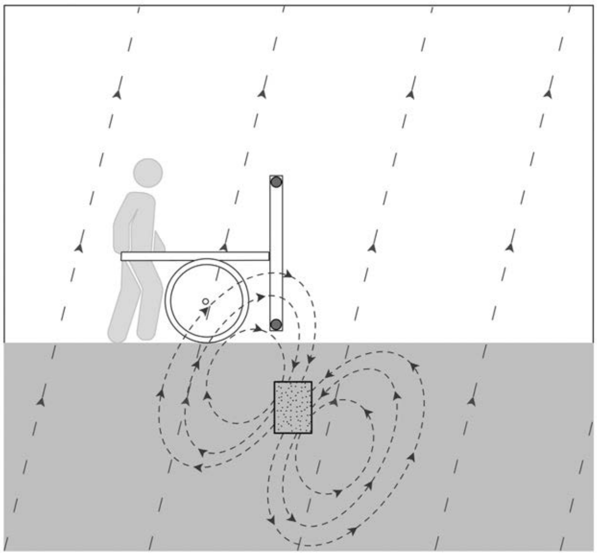

Figure 1.12. Gradiometer explanation diagram.

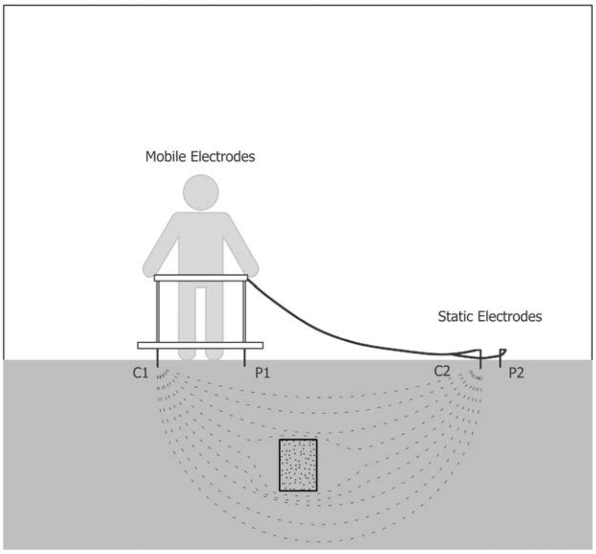

Figure 1.13. Resistance explanation diagram.

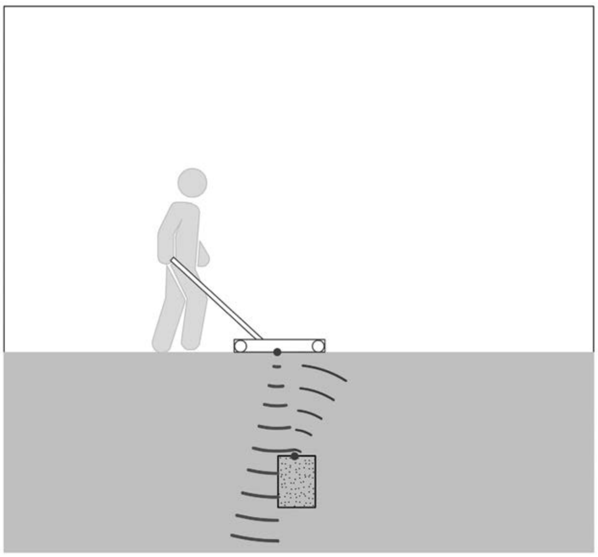

Figure 1.14. Ground-penetrating radar explanation diagram.

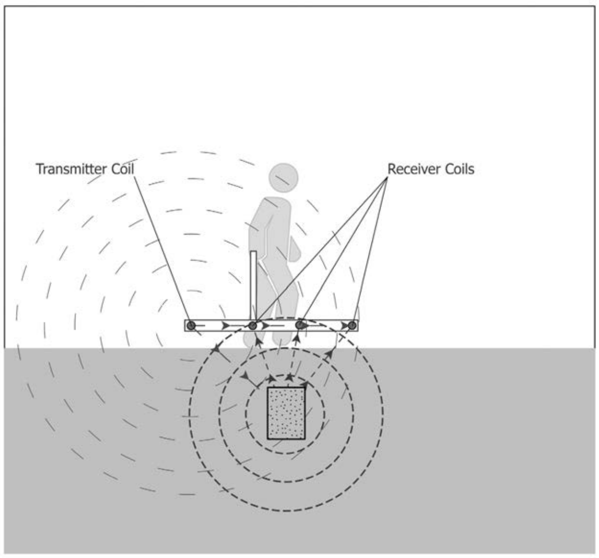

Figure 1.15. Electro-magnetic survey explanation diagram.

readings or high positive to high negative in the case of gradiometer data. Graphics employing a colour palette are sometimes useful (e.g. Figures 6.5.6 and 7.2.11). The same software offers several options for processing or treating the raw data, for instance 'destriping' to remove the effects of alternate darker and lighter bands resulting from gradiometer readings taken in, as is normally the case, a zig-zag fashion, or 'despike' where an extreme or set of extreme readings are replaced by a mean value (see Table 1.2; Schmidt *et al.* 2015: 100-104).

GSB Prospection, HES and Glasgow University also employed other techniques, but to a more limited extent. The most useful has been ground-penetrating radar (GPR) (Figure 1.14), which is capable of detecting the main features expected on the Antonine Wall (English Heritage 2008, Table 7). Not only can it estimate the depth of these features, it can also present its results graphically in different ways: first, as a scan or radargram (e.g. Figure 5.5.5) – a two-dimensional plot of response (reflector strength) as a function of distance across the ground and depth; and second, where readings have been collected over several parallel traverses, as a time slice, enabling an area to be viewed at progressively increasing depth (e.g. Figures 4.1.7 and 5.5.7).

Electro-magnetic survey (EM) is a technique that emits an electro-magnetic signal (the primary signal) from a transmitting coil that passes through the ground

Table 1.2. Operators, techniques, survey parameters and processing procedures

Operator	Magnetic (gradiometer); sample & traverse intervals; processing	Electrical resistance mapping; sample & traverse intervals; processing	Electrical resistance profiling	GPR	Other	Topographic
GSB	Bartington Grad 601-2; 0.25m x 1m; removing baseline shifts and interpolation. Foerster Ferex 4.0132 DLG	Geoscan RM15/ MPX15 multiplexed system, twin probe; 0.5m and 1.5m separations; 1m x 1m; de-spike, filtering, interpolation	Syscal Junior, IRIS instrument, dipole-dipole and Wenner array, 24 electrodes, 2m electrode spacing along 96m; RES2D-INV inversion program	Pulse Ekko 1000 with 225MHz antenna; 1m parallel traverses, continuous readings. Sensors & Software Noggin+ Smartcart, 250MHz antenna	Seismics: Geometrics Geode 24-channel recorder, 24 geophones at 2m spacing; shot spacing at 1m and 11m from each end; Interpex IXSeg2SegY software	Trimble GeoXH dGPS system (with Zephyr antenna and Geobeacon receiver)
University of Glasgow	Geoscan FM36 (1m x 1m), Bartington Grad 601-1 and 601-2 (0.25m, 0.5m); Geoplot v. 3 and 4: zero mean traverse, despike, destagger, interpolation; experimentation with Frost, Wiener and directional filters on gradiometer data from Balmuildy (Hinz 2006)	Geoscan RM15 twin probe, 0.5m; MPX 0.5m and 1.5m separations; 1m x 1m; Geoplot v. 3 and 4: despike, edge match, filter, interpolation. TR/CIA twin probe 0.5m; 1m x 1m	Geoscan RM15; Wenner array, probe separation 1m, 2m, 3m, 4m	Utsi Electronics Groundvue 3 with 240 and 400MHz antennae; 0.5m or 1m traverses. Reflex for Windows (v. 3.0, Sandmeier Software) for radargrams and time slices	Magnetic susceptibility: Bartington MS2D coil system (2m or 5m). Conductivity: Geonics EM38 with hand-held Allegro data logger	EDM total station; latterly Leica GS16
Hannon	Bartington GRAD 601-2; 0.5m x 1m; removing baseline shifts and interpolation. Terrasurveyor: destripe, destagger and despike					Leica GS16
Historic Environment Scotland	Sensys MXPDA system mounted on type-F non-magnetic cart; 0.125m x 0.5m, or 0.125m x 0.25m; Terrasurveyor: destripe/clip			MALÅ Ground Explorer system mounted on a Rough Terrain Cart Mini with single GX450 HDR Antenna; 0.1m x 0.5m, or 0.1m x 0.2m; ReflexW	GF Instruments CMD Mini Explorer for conductivity and magnetic susceptibility measurements; 0.1s x 1m, or 0.1s x 0.5m; Terrasurveyor: destripe/clip/ HPF	Leica GS16 GNSS streaming NMEA
GUARD and GUARD Archaeology	Geoscan FM36 (0.5m x 1m)	Geoscan RM15 twin probe, 0.5m; 1m x 1m				EDM total station
Centre for Field Archaeology		Geoscan RM15 twin probe, 0.5m; 1m x 1m				

Operator	Magnetic (gradiometer); sample & traverse intervals; processing	Electrical resistance mapping; sample & traverse intervals; processing	Electrical resistance profiling	GPR	Other	Topographic
Edinburgh Archaeological Field Society		TR/CIA twin probe 0.5m; 1m x 1m				
University of Bradford		Geoscan RM4				
Woolliscroft		Martin-Clark instrument				
Ancient Monuments Laboratory		Martin-Clark (dipole-dipole method)				

and buried objects and induces the propagation of a secondary signal (Figure 1.15). Both the primary and secondary signals are measured by a series of receiver coils allowing readings from multiple depths to be obtained. Changes in the amplitude of these signals can be used to detect sub-surface variations and can simultaneously measure apparent conductivity and magnetic susceptibility (Schmidt *et al.* 2015: 89-90). The technique has been deployed at Duntocher, Seabegs and Kinneil (Chapters 2.3, 5.5 and 7.2) with variable results.

Seismic refraction has found valuable application at one location – between Summerston and Balmuildy – where earth resistance had produced problematic results. This form of seismic survey (Schmidt *et al.* 2015: 94-95) is well suited to the detection of broad, relatively deeply buried structures such as the Ditch, as work on the Vallum on the south side of Hadrian's Wall at Rudchester demonstrated (Goulty *et al.* 1990; Goulty and Hudson 1994). Corresponding work with seismic reflection was carried out with some success at the ditch at Inveresk fort (Harith 1998: 33-57, Fig. 2.18).

Electrical imaging, also known as vertical electrical sounding (pseudosection), in which electrical resistance is determined as a function of depth (Schmidt *et al.* 2015: 74-75), was also usefully applied in areas between Summerston and Balmuildy (Figure 2.8.7), as well as at Auchendavy (Figure 4.1.8).

1.5 Interpretation of geophysical data

Several considerations play a role in interpreting geophysical data. Drawing on the guidelines of Schmidt *et al.* (2015: Table 4), there are the natural factors, of which the solid and drift geology, soil type, surface conditions and topography are most relevant to the land encompassing the Wall. Assessment of the geology, using information drawn either from https://digimap.edina.ac.uk/roam/map/geology or the British Geological Survey, was an essential first step in any proposed survey, resulting in the potential exclusion of gradiometry at sites situated on or close to outcrops of igneous rock. At the same time this assessment highlighted those sites where the till cover might include igneous debris giving rise to a noisy (magnetic) background. This situation occurred at a number of locations in the western half of the Wall. Soil types were taken from http://map.environment.gov.scot/Soil_maps/. The other class of factors affecting interpretation of the archaeology, notably landscape history, agricultural practices and modern interference, enter the discussion in the final chapter.

The graphical output of the three main gradiometer and resistance data sets presented in this volume – those of GSB, Glasgow University and HES – are all in the form of grey-scale images (see Table 1.2). Much smaller in number are the GPR, seismic, electro-magnetic and electrical profiling graphics which are presented in conventionally accepted manners (Schmidt *et al.* 2015; Gaffney and Gater 2003, colour plates 15-17). Together, these make up the primary data and it is from them that the nature and shape of the responses - the anomalies - can be identified.

Interpretation proceeds by highlighting with annotation primarily those anomalies that are considered likely to be Roman in origin and thereby merit discussion in the defined scope of this volume. This informed interpretation is, we believe, justified in view of our present considerable understanding of the nature of Roman military sites, and as a result, it may differ from those put forward in the original reports (e.g. Chapters 2.4, 3.1, 3.5, 4.1, 6.3). Regarding the interior of forts, that knowledge takes account of the effects of possible reuse, alteration or decommissioning of a structure/feature. At the same time, our procedure acknowledges those anomalies arising from geology and from pre- and especially post-Roman (including modern) activity in so much as they lie close to or are associated with Roman features. For the Antonine Wall this is an important issue given the extent to which these features have been affected since burial by, for example, stone robbing, agricultural activity and modern utility pipeline construction. The responses from these pre- and post-Roman activities have not been ignored, rather they have usually received only cursory interpretative attention and are only occasionally annotated in the graphics.

1.6 Archaeological targets and their geophysical responses

The potential targets of the survey can be conveniently divided into a number of sections: the linear barrier with its different component parts (Rampart, Berm, Ditch and Upcast Mound);[3] the forts and their annexes; the fortlets; the expansions; the minor enclosures; the Military Way; the construction camps; and the extra-mural settlements. Each of these is briefly considered below and treated further in Chapter 8:

1.6.1 The linear barrier (Hanson and Maxwell 1986: 75-83; Breeze 2006: 71-78; Robertson 2015: 17-22; Romankiewicz *et al.* 2022)

The Ditch was V-shaped in profile, both sides sloping at an angle of *c.* 30° (Figure 1.16). Both its depth and width varied, the latter ranging for example from 4.3m at Croy Hill to 14.6m at Bar Hill, but typically in the central sector these dimensions were *c.* 3.6m and 12m respectively. Upcast material created from the digging of the Ditch was deposited on its northern edge. This Outer or Upcast mound was usually flattened out to a broad spread, but sometimes piled up to enhance the north face of the Ditch, as at Watling Lodge. The latter can create the impression of a second, less substantial ditch to the north, which is sometimes seen in the cropmark record (e.g. Figure 2.8.2). This same feature may have no recognisable geophysical response since it merely reflects the displacement of subsoil from the Ditch, although it is worth noting its possible detection by seismic, GPR and electrical profiling at Summerston (Chapter 2.8) and as a slight positive linear anomaly at Bonnyside (Chapter 6.2). At several forts a causeway was provided across the Ditch in front of the fort's north gate.

The gradiometer response at the centre of the Ditch is usually large, as befits the size and the depth of this feature; its polarity, however, is less consistent. In principle, the response would be expected to be positive, reflecting the enhanced magnetisation, or more specifically the greater magnetic susceptibility, of the infill with its accumulated more organic content compared to the subsoil through which it was cut. This was found to be the case for the Vallum and fort ditches at Birdoswald on Hadrian's Wall (Biggins and Taylor 2004b: 162-64), and at forts elsewhere, such as Whitley Castle in Northumberland and Llanfor in north-west Wales (Hale 2009; Hopewell and Hodgson 2012). Closely associated with the positive response may be a parallel negative one arising from the side and bank. By contrast, the magnetic response of the Antonine Ditch and fort ditches presented in this volume is reversed, the centre of the Ditch being negative usually with positives on one or both of its sides (e.g. Chapters 3.1; 3.4; 4.1; 4.2; 7.1 and 7.2). This issue is discussed further in Chapter 8.2.4.

How earth resistance responds across the Ditch depends critically on the nature of the infill and on climatic conditions; the norm is a decrease reflecting a relatively loose, well-drained infill (e.g. Chapter 3.1), but an exception has been encountered (Chapter 2.8). On the other hand, a more compacted infill with lower moisture content will register an increase as occurs in some fort ditches (e.g. Chapter 2.5). The same factors affect the GPR response, the Ditch giving a strong reflection (e.g. Chapter 2.8) and low amplitude signal (e.g. Chapter 3.2).

The Rampart had a shallow stone foundation, 4.3-4.8m wide, defined by two parallel rows of roughly faced kerbstones with unshaped stones or cobbles packed in between (Figure 1.17). Culverts, also built of roughly squared stones and both floored and capped with slabs, were built into the base at irregular intervals. Above the base would have lain some twenty or more layers of turf, each with a thickness of no more than 15cm, resulting in an overall height of at least 3m, though the character of the upper section of the Rampart is uncertain. Whether it was provided with a palisade and walkway, and how that might have been supported, has long been assumed but is much disputed (e.g. Robertson 1960: 12; Hanson and Maxwell 1986: 83). In areas where good quality turf was less readily available, such as towards the eastern end of the Wall, it has long been thought that the Rampart was made of compacted earth revetted by cheeks of clay or turf. More recent micromorphological analysis, however, suggests that turf was used throughout the structure, despite variations in its quality (Romankiewicz *et al.* 2020). Since the Rampart rarely survives as an earthwork, it is the stone foundation and crucially its physical condition that are primarily responsible for

[3] References to these linear elements of the Wall are deliberately capitalized throughout the volume to avoid any confusion with similar features related to associated structures.

Figure 1.16. One of the best surviving sections of the Ditch at Watling Lodge, where the Upcast Mound (right) was augmented. View from the north-east.

the geophysical response, observed usually as a mottled positive in gradiometer surveys (e.g. Chapters 3.1, 3.4, 6.2 and 7.2), an increase, albeit of varied strength, in resistance (see, in particular Figure 3.4.5 Areas 1B and 2) or as a moderately strong reflector in the radargram (Figure 3.2.5). The effect on the geophysical response of the occasional better preservation of the turf superstructure is discussed in Chapter 8.2.4.

The Berm, the space between the Wall and the Ditch, varies in width from 6.1m to over 9m. It may appear as an area that is relatively uniform magnetically and in terms of resistance. Pits set in a distinctive quincunx pattern (*cippi*), intended to hold multi-forked branches with sharpened ends forming entanglements similar in effect to barbed-wire, have been recorded by excavation at several locations along the Berm (Bailey 2021: 23-25), but identified only tentatively by geophysical survey (see Chapters 2.3, 5.5 and 6.2). Very similar defensive pits have long been known at Rough Castle (Buchanan *et al.* 1905: 456-58 and Fig. 1), located not on the Berm but immediately beyond the Ditch to the north-west of the fort. These, however, are interpreted as *lilia*, concealed pits intended to hold sharpened stakes (Madconald 1934: 235; Bidwell 2005: 56-63), the Roman equivalent of anti-personnel mines. It is not possible to differentiate between the different types of defensive pits on the basis of geophysics alone, other than by virtue of their location. The *lilia* are currently unique to Rough Castle and may be related to the vulnerability of its specific topographic location adjacent to the valley of the Rowan Tree Burn. Nonetheless, the possibility that other forts may have been provided with similar additional defences needs to be considered.

1.6.2 Forts and annexes (Hanson and Maxwell 1986: 86-93; Breeze 2006: 81-84 and 90-97; Robertson 2015: 22-25 and 29-30)

Seventeen forts are currently known to be located along the line of the Wall, all bar two (Bar Hill and Carriden) attached to its rampart (Figure 1.1). They vary considerably in size (0.12-2.6ha in area) (Figures 2.3.4 and 6.5.2 illustrate the extremes). All but two (Castlecary and Balmuildy) had ramparts like the Wall composed of turf, beyond which were usually at least two ditches, though these were much smaller than the Ditch in front of the Wall itself. At least nine forts (including Falkirk and Carriden) were provided with attached annexes, some by more than one, defined in the same way. Most of the forts have experienced some level of excavation, but predominantly this took place in the first half of the 20th century and usually on a small scale. Like the Wall itself, the ramparts of the forts/annexes may be expected to manifest themselves as linear positive, or mottled positive, magnetic anomalies and higher

Figure 1.17. Extant remains of the Rampart base and a culvert in New Kilpatrick cemetery. View from the east.

resistance anomalies (e.g. Chapters 2.5; 3.1; 5.1 and 5.4), though this is not invariably the case (e.g. Chapters 2.3 and 6.5). This will be discussed further in Chapter 8.2.4. Like the Antonine Ditch, the fort's ditches are normally observed as negative gradiometer and, where tested, low resistance anomalies (e.g. Chapters 2.3; 2.5; 3.1; 4.1; 5.4; 6.3; 6.5 and 7.6). The exceptions are where the ditches have been, perhaps deliberately, infilled with burnt debris and/or rubbish thereby giving a positive response (cf. Dalswinton – Hanson *et al.* 2019: 301 and Fig. 10), though none have been recorded along the Wall.

The central range of buildings within each fort was usually stone built, as was the internal bathhouse where one was provided. High resistance would be the anticipated electrical response of the walls of such buildings, while for the gradiometer they would give a negative response. Again, this was not always the case and the reasons are further discussed in Chapter 8.2.4. The barracks located to the front and rear of the forts were of timber construction, their walls usually defined by individual post-holes rather than construction trenches. These are very rarely detected in the geophysical surveys for reasons that are also discussed more fully in Chapter 8.2.4. Pits dug to contain rubbish should give a strong gradiometer response because of enhancement caused by bacterial action of their contents, but if small can be difficult to differentiate from general background noise. Cooking ovens, which are usually disposed around the perimeters of the forts, should give a thermoremanent magnetic signature and thus would usually be easily detectable, but have proved elusive.

Though several annexes contained bathhouses, little more is known of their interiors. As a result, there is considerable debate about their function. Some see annexes generally as providing protection for civilians (e.g. Sommer 2006: 123), but the broader consensus is that, in the first and second centuries at least, they served entirely military requirements (e.g. Hanson 2021). Where more extensive excavation has taken place, as at Mumrills and Falkirk, a range of features have been found suggestive of semi-industrial activity, such as cobble surfaces, pits and metalworking, as well as some timber buildings. The pits, and particularly the pyrotechnologically based activities, should be amenable to detection by gradiometry and magnetic susceptibility methods. Kilns and furnaces give a large north-south oriented dipolar response, as do the hypocaust and other fired material relating to a bathhouse (e.g. Chapters 6.3 and 6.5). The latter, where damaged, may appear as an area of enhanced magnetic disturbance (e.g. Chapters 4.1 and 6.3).

1.6.3 Fortlets (Hanson and Maxwell 1986: 93-96; Breeze 2006: 85-86; Robertson 2015: 25-27)

It is now generally accepted that the original plan for the Wall included a complete sequence of fortlets at approximately one Roman mile intervals, though only 13 have been confirmed archaeologically, including by geophysics (e.g. Figure 1.9) (Hannon *et al.* 2020: 67-73). They were small enclosures measuring some 21m by 18m, surrounded usually by one, but occasionally by two, ditches and provided with two gateways, one through the Wall and one for access from the south. In all the examples where the relationship has been tested by excavation, they have been shown to be earlier than or contemporary with the Wall Rampart. What little is known of their interiors indicates the presence of timber buildings on either side of a central roadway. The magnetic and resistance signatures of their ramparts, ditches and internal features are similar to those of a fort (e.g. Chapters 2.2; 2.3; 2.5; 3.4 and 7.2), though internal buildings are less readily visible in the absence of stone foundations.

1.6.4 Expansions (GAS 1899: 77-79, 84-85 and 145-49; Steer 1957; Robertson 1969: 37-39; Hanson and Maxwell 1986: 97-99; Breeze 2006: 87-88; Robertson 2015: 27-29)

Three pairs of small turf platforms attached to the rear of the Rampart were recognised during fieldwork by the Glasgow Archaeological Society in the early 1890s. The function of these expansions, as they came to be called, remains uncertain, though is most likely related to long-distance signalling. They were constructed on a cobble foundation some 5.2-5.5m square that abuts the rear of the Rampart base. This should indicate that they were later additions, though this chronological relationship has been disputed as the superstructure of the most extensively excavated example at Bonnyside East appears to be bonded into the turf of the Wall. However, this observation is itself disputed (Hanson 2020: 13-14, ftnt 57) and the evidence from both of the excavated examples on Croy Hill clearly shows that their turf superstructures were secondary additions (GAS 1899: 77-79 and 84-85; Robertson 1969: 37-39). No further examples have been found since the 1890s, though one was tentatively identified during excavation at Inveravon (Chapter 7.1). Any gradiometer or resistance response should be similar to that of the Rampart, though at the one example that has been subject to geophysical survey, Bonnyside East (Chapter 6.2), the response is not entirely clear.

1.6.5 Minor enclosures (Hanson and Maxwell 1983; 1986: 96-98; Breeze 2006: 88-89; Robertson 2015: 28-29)

Small, closely spaced, ditched enclosures abutting the rear of the Wall have been recognised from the air, but in only one section of the Wall adjacent to the fortlet at Wilderness Plantation. Their function is unknown. The one excavated example indicated that the enclosure was contemporary with the Wall and defined an area 8.6m by 11.7m, though the only internal feature identified was a slight earth/turf bank (Figure 3.2.3). None have so far been identified with certainty by geophysical survey (but see Chapter 7.2).

1.6.6 Military Way (Hanson and Maxwell 1986: 83-84; Breeze 2006: 78; Robertson 2015: 22)

The Military Way ran roughly parallel to the Wall, forming an essential lateral communication component of the frontier system. Its precise course varies, but it usually runs between 15m and 45m to the south of the Wall, though bypass roads, generally positioned further south, have been recorded at several fort sites. The road was usually between 4.9m and 5.5m wide, with a pronounced camber, constructed on a base of rough stones topped by rammed gravel and smaller stones (Figure 1.18). Drainage ditches were commonly provided on either side and quarry pits associated with its construction are not infrequently recorded nearby (Figure 1.8).

In principle, the road should be clearly defined as a high resistance anomaly because of its stone construction. Gradiometer and GPR survey would also be expected to detect the structure with relative ease; but, in practice, this is not the case since the road surface has frequently been ploughed away or at least significantly damaged, as several instances reported in this volume attest (e.g. Chapters 3.2 and 7.2). The exceptions are the well-preserved sections of Military Way at Seabegs Wood, where the road surface is identifiable in the gradiometer, EM and GPR data, and to a lesser extent Bonnyside East (Chapters 5.5, 6.2 and 8.2.4). Similarly, good results have occasionally been obtained elsewhere in Scotland. At Barwhill, Gatehouse of Fleet, a *c.* 100m stretch of Roman road (running from Glenlochar to Loch Ryan), visible in aerial photographs and located just south of a Flavian fortlet, appeared as a linear *c.* 7m wide slightly positive magnetic anomaly flanked by negatives (presumably representing the road's drainage ditches) (Cowley *et al.*

Figure 1.18. Excavated section of the well-preserved Military Way bypass road to the south of the fort at Croy Hill. View from the north-east.

2019). Immediately north of the road were oval positive anomalies that were interpreted as quarry pits. The corresponding resistance data, however, was much less informative.

1.6.7 Camps (Hanson and Maxwell 1986: 177-20; Jones 2005; Breeze 2006: 32 and 66-68; Robertson 2015: 38-39)

Some 21 temporary camps have been recorded in the immediate vicinity of the Wall, mainly located to the south. Most of them are relatively small, some 2-2.5ha in area, and are widely accepted as construction camps intended to house the soldiers building the Wall. As noted above, all have been found by aerial reconnaissance as cropmarks (Figure 1.8), as a result of which more are known towards the eastern end of the Wall. That camps overlap in two locations (Dullatur and Inveravon) indicates that they were not all in contemporary use.

Since the camps are defined by the single, relatively narrow, ditches that surround them, their geophysical signature should not be dissimilar in principle to that derived from the ditches around forts. The interiors of temporary camps are increasingly being shown to contain groups of rubbish pits and/or ovens, which are particularly susceptible to magnetic survey (e.g. Hanson *et al.* 2019: 297 and Fig. 7). However, very few along the Wall line have been subject to survey (see Chapter 7.4).

1.6.8 Extra-mural settlement (Hanson and Maxwell 1986: 186-90; Breeze 2006: 129-36; Hanson 2020a; Allason-Jones *et al.* 2020)

The presence of civilians along the Wall is well attested artefactually and epigraphically, but only poorly confirmed by the recognition of associated settlement foci. Fragmentary traces of timber buildings and even occasional stone foundations have been noted in excavations at a few sites (Bearsden, Croy Hill and Westerwood), but, unlike on Hadrian's Wall, there is no coherent picture of what such settlement would have looked like. There is, however, much stronger evidence around several fort sites (Auchendavy, Croy Hill, Rough Castle and Carriden) of small land divisions or fields defined by slight ditches, banks or gullies, indicating contemporary agricultural or industrial activity. None of these features are likely to provide a strong geophysical signal and so the topic is left to Chapters 8.1.6 and 8.2.4. The best hope of identifying extra-mural activity with the gradiometer would seem to come from associated pyrotechnological activity, such as pottery manufacture or on-site cremation. Relevant evidence has not yet been forthcoming, though individual examples may be difficult to distinguish from the general background noise.

1.7 Aims and structure of the book

The overall aims of this volume are threefold. Firstly, it sets out to make more readily accessible and widely available the data from the numerous geophysical surveys that have been undertaken at a large number of sites on the Antonine Wall over the last 20 years or more so that they may better be assimilated into our knowledge base. The results and archaeological evaluations of much of this work exist for the most part as unpublished reports, often referred to as 'grey literature', which is accessible primarily only to the institutions that funded the surveys or to specialists who know how to access them. Accordingly, the data from those sites that have been subject to geophysical survey (Figure 1.19) are illustrated and considered here in Chapters 2-7, laid out in gazetteer format in geographical order from west to east.

Secondly, this volume seeks to re-examine and re-analyse that data. Thus, it offers more focused interpretations for each site based on a wide background knowledge of the monument. Those who undertook the original surveys were, for the most part, specialists in the acquisition and manipulation of geophysical data, rather than in Roman military archaeology. It is our strong contention that analysis of this data is greatly enhanced when viewed from the perspective of those with a more detailed and intimate knowledge of the relevant subject of study, in much the same way that excavations tend to produce more informative and insightful results when the excavator is a specialist in the type of site under investigation; this view is echoed in a wider context elsewhere (Jones 2024). Thus, one of our number is co-author of one of the standard textbooks on the Wall (Hanson and Maxwell 1986), co-editor of the most recent examination of its remains (Hanson and Breeze 2020) and co-editor of the HES's Antonine Wall Research Agenda (ScARF 2023); while another, the subject of whose PhD was the analysis of a LiDAR survey of the Wall (Hannon 2018), currently leads HES' geophysical survey fieldwork.

The structure of the gazetteer chapters (2-7) follows a consistent format, where possible. A grid reference is provided to locate the survey, along with the Canmore identification number(s) where available. Relevant site-specific archaeological references are listed at the beginning of each entry to avoid cluttering the subsequent text. References to basic overviews of the Antonine Wall (Macdonald 1934; Hanson and Maxwell 1986; Breeze 2006; Robertson 2015) should be taken as standard for virtually all sites, so are not included to avoid unnecessary repetition.

The character, extent, date and source of the geophysical surveys undertaken is then summarised in tabular form. The survey techniques are gradiometry (G), earth resistance (R) ground-penetrating radar (GPR), electromagnetics (EM), magnetic susceptibility (MS), electrical profiling (EP) and seismic refection (SR). Their operating parameters are sample and traverse intervals that refer to the distances between measurement positions along a traverse and between traverses respectively. In the case of multi-sensor gradiometer systems, that information is often expressed as sample interval followed by sensor separation (ss). For the earth resistance technique the default setup is twin probe with probe separation of 0.5m. If another probe separation was also used, this is stated following the sample and traverse intervals.

In each case there then follows a brief introduction to the site, which considers how the survival of the remains has changed over time and what additional information has been provided by other forms of investigation. Site excavation plans, aerial photographs or LiDAR images are provided as appropriate. Any issues affecting the geophysical surveys (locale/terrain; geology and soils) are then considered before the results of those surveys are described and interpreted/reinterpreted. Precise location plans of the surveys are provided, along with detailed annotated plots of the gradiometer and resistance results. Each plot is accompanied by a grey-scale palette which gives the values (in nanoTesla (nT) or ohms) represented by the scale's black and white tones. The survey results are then integrated with any other relevant remote sensing, mapping and excavation data, and any enhancement to previous knowledge and understanding of the site is highlighted.

Finally, having assembled, presented and re-analysed the data in the gazetteer chapters (2-7), the third aim of the volume is to draw some wider conclusions, both archaeological and geophysical. Accordingly, Chapter 8 is divided into two parts. The first seeks to assess the often-undervalued contribution of geophysical survey to our further understanding of the Antonine Wall and its associated structures, drawing attention to a number of areas where it has enhanced that understanding. The second attempts to use the long history of the application of such survey to a single monument in a limited geographical area by a number of different practitioners to appraise the nature of the methodology itself, considering both its strengths and its weaknesses.

Figure 1.19. Sites along the Wall subject to geophysical survey indicated by black circles (map after D.J. Breeze, with additions).