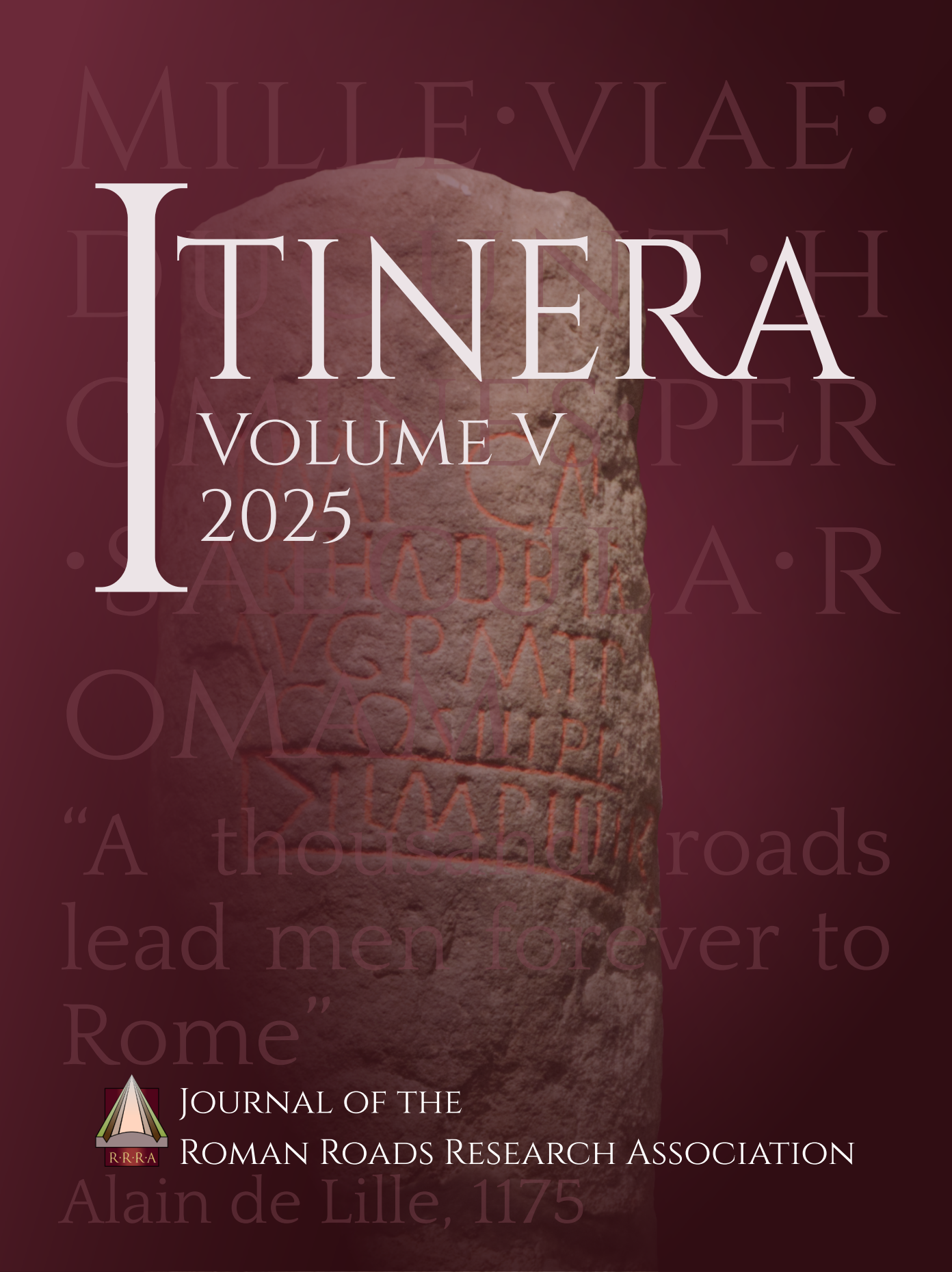


ITINERA

Volume V
2025

"A thousand roads lead men forever to Rome"

Alain de Lille, 1175

Journal of the
Roman Roads Research Association

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Contents

v Editorial

Articles

1 - 42 WAYNE KIRK, A Lidar Based Appraisal of the Roman Roads in Northamptonshire

43 - 74 NEIL GODFREY, Roman Roads and Rural Romano-Celtic Temples in Roman Britain - Perspectives and Case Studies

75 - 102 ROBERT ENTWISTLE, The Principles of Roman Surveying as Displayed in Long-Distance Alignments

103 - 126 FLORIN-GHEORGE FODOREAN, The Roman Imperial Road in Dacia: Lederata / Dierna - Porolissum. A General Overview

127 - 152 ADRIANA PANAITE, Roman Roads in Moesia Inferior: the History of Research and the Road Network

153 - 182 MIKE LUKE, A Review of Roman Roads within and from the 'Small Town' at Sandy

183 - 202 PAUL SMITH, A Review of the Status of RR193: Greensforge, Staffordshire to Newtown, Powys

203 - 220 KEITH ABBOTT, Trails of Breadcrumbs: Predictive Methodologies used to Enhance Analysis and Discovery of Past Movement across Roman Britain

Roman Roads in 2024

221 - 280 Roman Roads in 2024: a Review of Recent Research and Fieldwork

281 - 284 DAVE ARMSTRONG & MIKE HOLMES, Newly Allocated Margary Road Numbers

Reviews

285 - 288 J. Tanner & A. Gardner (eds.), *Materialising the Roman Empire*. (By Paul Booth)

289 - 290 William S. Hanson, Richard E. Jones & Nick Hannon, *Exploring the Antonine Wall with Terrestrial Remote Sensing.* (By John Poulter)

291 - 300 Index

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Editorial

Robert Entwistle



Welcome to the 2025 edition of *Itinera*, Volume V. *Itinera* continues to hold a unique position among academic journals of Roman studies, with roots in both the academic and grassroots communities. We focus upon the study of Roman roads, transport technology and systems of surveying. We welcome reports and contributions from all researchers able to extend knowledge in these areas to professionals and the public alike, through the format of a formal academic paper.

Volume V, if slenderer than the bumper 2024 edition, is typical in its range of papers. Thus, Wayne Kirk extends our knowledge of Roman Northamptonshire in the light of modern findings, through a wide-reaching paper appraising its road network. Mike Luke, well respected for his excavations and publications on Roman Bedfordshire, shows how a developed understanding of the 'small town' of Sandy leads to an improved appreciation of the local roads. The same theme of road networks is explored in a different way by Keith Abbott, who argues that minor roads and trackways are seriously under-represented in our present appreciation of Roman roads.

Neil Godfrey, by contrast, addresses a wholly different issue: the relationship between roads and Romano-Celtic temples, with roads providing not only transport and passing clients, but also planned landscapes within which temples stood. My own paper is different again, examining ancient surveying methods through the features of extant surveyed works, classical literary sources, and modern surveying techniques. This methodological paper ends my series of papers on Long-distance Alignments. We are also pleased to have a paper from an independent researcher, Paul Smith – one of our own members – presenting his thesis of a road formed over time, from the Iron-Age into the Roman period and beyond.

In this volume we further welcome two authoritative papers from leading academics in Romania, demonstrating the growing understanding of Roman roads in a part of the empire that has received limited attention in the UK. In understanding the growth of road networks in a territory newly brought within the empire we see the link between conquest and road construction, and reflect on the impact of recent political change upon research.

As always, I warmly celebrate the work of our academic advisors and our willing team of volunteers who carry out many critical functions: proofreading, creating the Index, reporting updates from across the country, and managing distribution of printed copy. *Itinera* would not be possible without the willing labours of these individuals, and above all without the editorial team who manage the life of our journal across the year. The process moves from gathering papers and archaeological updates, through review, selection, editing and typesetting, through to final publication. Dr Mike Bishop – writer, publisher and archaeologist – was a founder member of our editorial team, guiding us through the formative first four years of our existence. His expert advice on publishing and all matters Roman helped steer us through a period when everything was new. His international contacts extended knowledge of our journal to contributors as far away as Spain (and most recently) Romania. *Itinera* owes him a great debt as he moves on to other things this year.

With Mike leaving, we are delighted to have welcomed to our team Professor James Gerrard of the University of Newcastle. James Gerrard brings great academic distinction, strengthening us with his experience and calm judgements. Already he has inspired the initiative of an annual Prize for the best Dissertation reflecting Roman Transport studies. Details of the prize (readily available on request)

have been distributed through SALON and the RRRA Newsletter and will shortly be available on the RRRA website. We hope to see this prize awarded for the first time in 2025.

I take this opportunity of warmly welcoming submissions, projected or actual, for Volume VI of Itinera, from all corners of Britannia and the wider empire. You will find '*Notes for Contributors*' on the RRRA website.

In the meantime, I invite you to enjoy everything within Volume V.

Robert Entwistle

(Hon Editor, *Itinera)*

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The Principles of Roman Surveying as Displayed in Long-Distance Alignments

by Robert Entwistle
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Abstract

This paper seeks to place Roman Long-distance Alignments in the context of both known Roman surveying methods and relevant modern practice. Although their existence has never been seriously challenged, Long-distance Alignments (laid out for presumably strategic reasons) can now only be identified indirectly through the roads and forts which used them to determine route and location. We briefly examine their nature, but chiefly consider how these remarkable works may have been laid out and why they took the form they did. Conclusions will relate to the strengths and weaknesses of Roman surveying methods.

Over twenty examples of Long-distance Alignments have been identified over the last two decades, but this paper mentions only a few to illustrate points being made. A fuller range can be found in Britannia Surveyed *(Entwistle 2019), and in* The Identification of Long-Distance Roman Alignments in Britain *(Poulter 2022).*

The Nature of Surveying

Topographical surveying, as understood today, seeks to determine and establish the boundaries, area and elevations of land and artificial features through the measurement of angles and distances. Accuracy depends upon methods used, the precision with which they are employed, and the levels of accuracy anticipated and required at the outset. In Roman times, no less than now, accuracy would depend on both the purpose of the task and the limits of the technology. Much in the essential nature of surveying retains common ground between past and present, although modern surveying reaches levels of sophistication undreamt of in the past. The Latin words for surveyor: *mensor* (relating to measurement) and *finitor* (the establishment of boundaries), indicate that fundamental aspects remain relevant to this day, although the intervening centuries have seen a revolution in methods, equipment and technology. However, as similar problems invite similar responses, we might expect that certain principles from the ancient world have remained relevant.

Modern surveying possesses technological tools inconceivable to the Romans, but the craft still falls fundamentally into topographical surveying and 'construction stakeout', a distinct branch which creates ground plans for construction work. We are familiar with Roman work that falls into that latter category, particularly the laying out of roads, camps and forts. Long-distance Alignments, by contrast, fall under topographical surveying and seem to represent a strategic phase in which the

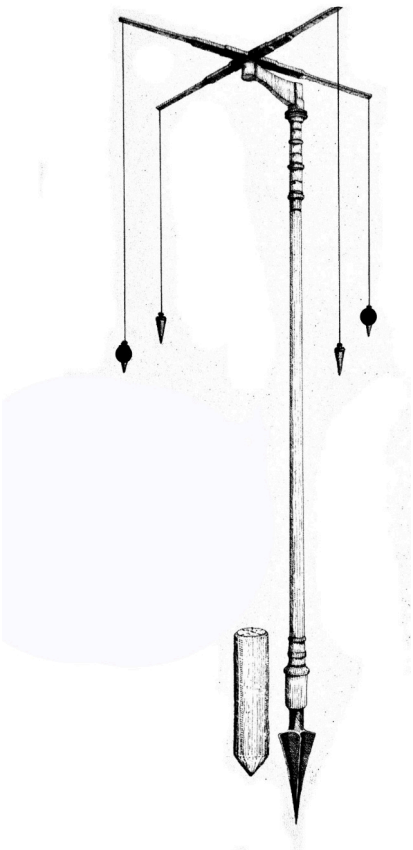
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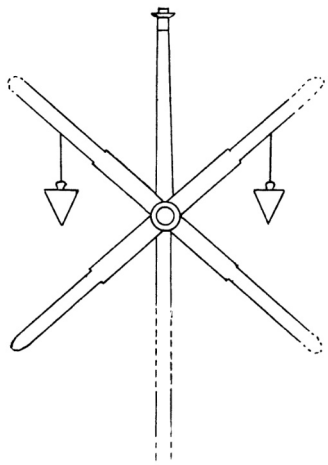
margins of empire were being explored and prepared for potential military operations, for infrastructure such as roads and forts, or for administrative division (Entwistle 2022, 55-57).

Roman Surveying Practice

Our knowledge of Roman surveying practice is largely governed by the chance survival and copying of texts. Although the Romans are remembered as great builders of roads forming strategic links across the empire, no surviving construction manual guides us towards understanding their methods. The ancient source most quoted on the matter is a poem by Statius celebrating the completion of the *Via Domitiana*. It would surely come as a surprise to Statius that his poem *Silvae* should become the principal source on the mechanics of road construction, a purpose that he is unlikely to have envisaged. Thus, faced with limited literary sources, we remain heavily dependent upon archaeology for interpreting the roads.

There is even less guidance in the ancient literature about the process of creating long-distance surveys, although information concerning related aspects of surveying methodology has survived. The *Corpus Agrimensorum*, a difficult and corrupt group of texts (treated and translated in Campbell, 2000), tells us much about the work of the *agrimensores*, professional land surveyors. They were responsible for, among other things, laying out boundaries and the formal grid pattern of agricultural land known as centuriation. The texts provide an indication of how accurate alignments should be





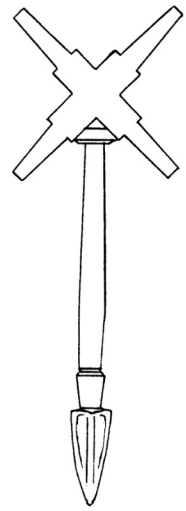


Fig. 1. Above. Drawings (courtesy Michael Lewis) showing the groma *as illustrated on tombstones from Ivrea and Pompeii*

Fig. 2. Left. Della Corte's widely-accepted reconstruction of the Pompeii groma *(after Della Corte 1922).*

formed for such purposes. We can still find sites where such grids are preserved recognisably (Bradford 1957, 145-216), notably in the Po Valley and in Tunisia. The area around Cesena (Italy) is a good example. In Orange (*Aurasio*, France) a fragmentary centuriation plan engraved upon marble has survived.

The *groma*, the main tool of the *agrimensores*, was a device comprising a vertical pole and a rotating horizontal cross piece. Cords ending in plum bobs fell from each of the four arms of the crosspiece, allowing surveyors to align pairs of cords for the sighting of alignments. The *agrimensores*, were proud of their craft – so much so that we have two preserved tombstones of practitioners from Ivrea and Pompeii showing carved representations of their signature tool, providing indication of their design (Fig. 1). Excavators in Pompeii found what are thought to be actual constituent parts of a *groma*, studied by Della Corte and resulting in his widely accepted reconstruction (Fig. 2). Despite all this, uncertainties remain about the details of the design (Lewis 2001, 129), but its overall capabilities are well understood.

Although the *groma* is best attested among civilian agrimensores, military surveyors also used it. The writer known as Pseudo-Hyginus mentions that in a military camp, the road crossing in front of the praesidium was known as the *groma* as the position of the gates was surveyed from this point (*De munitionibus castrorum*, 12.2). Much methodology would have been common to both civilian and military surveying, and the *groma* may reasonably be seen as the core surveying instrument of the legionary *mensores*. Their expertise is acknowledged by Hyginus, in the reign of Trajan, who writes of '*a volunteer ex-legionary* (evocatus*), who had sound military training and was most skilled in our profession*', who added more detail than usual to the bronze maps of land allocations in Pannonia *(De Condicionibus Agrorum*, quoted Dilke, 1971, 42).

Long-distance Alignments

Long-distance Alignments form a distinct branch of Roman surveying not recognisably discussed in the classical sources. More than twenty examples have now been identified in the north and south of Britain, some within connected networks. There is no attempt to list them in this paper: for that the reader is referred to Entwistle (2019), and Poulter (2022). Typically, they are long alignments, sometimes scores of kilometres long, whose existence is often deduced from long stretches of road demonstrably following a longer (but now invisible) surveyed line accurately connecting known Roman bases (see the Leicester-Cirencester example below). They are preserved visibly on the ground only where roads have been built upon them. Where a Long-distance Alignment turns or branches into a secondary line, the angle of turn is typically one of the four angles (other than right-angles) found in the familiar 3:4:5 and 8:15:17 triangles, both members of the 'Pythagorean Triple' family. These angles appear very regularly in connection with Long-distance Alignments (Entwistle 2019, 24-27) and are discussed further below.

The creation of Long-distance Alignments by Roman surveyors will presumably have followed an immediate need, most likely relating to strategic evaluation of territory and the recording of key features in preparation for military or administrative activity. We know Long-distance Alignments also to have been used in guiding road layout, and in the location of forts such as Ebchester and Piercebridge (Fig. 4) on Dere Street (Poulter 2009, 30). Road construction sometimes followed years or decades after the surveying of the line (Poulter 2009, 28), therefore lines must have been recorded on the ground and in Roman records to permit exploitation as need arose.

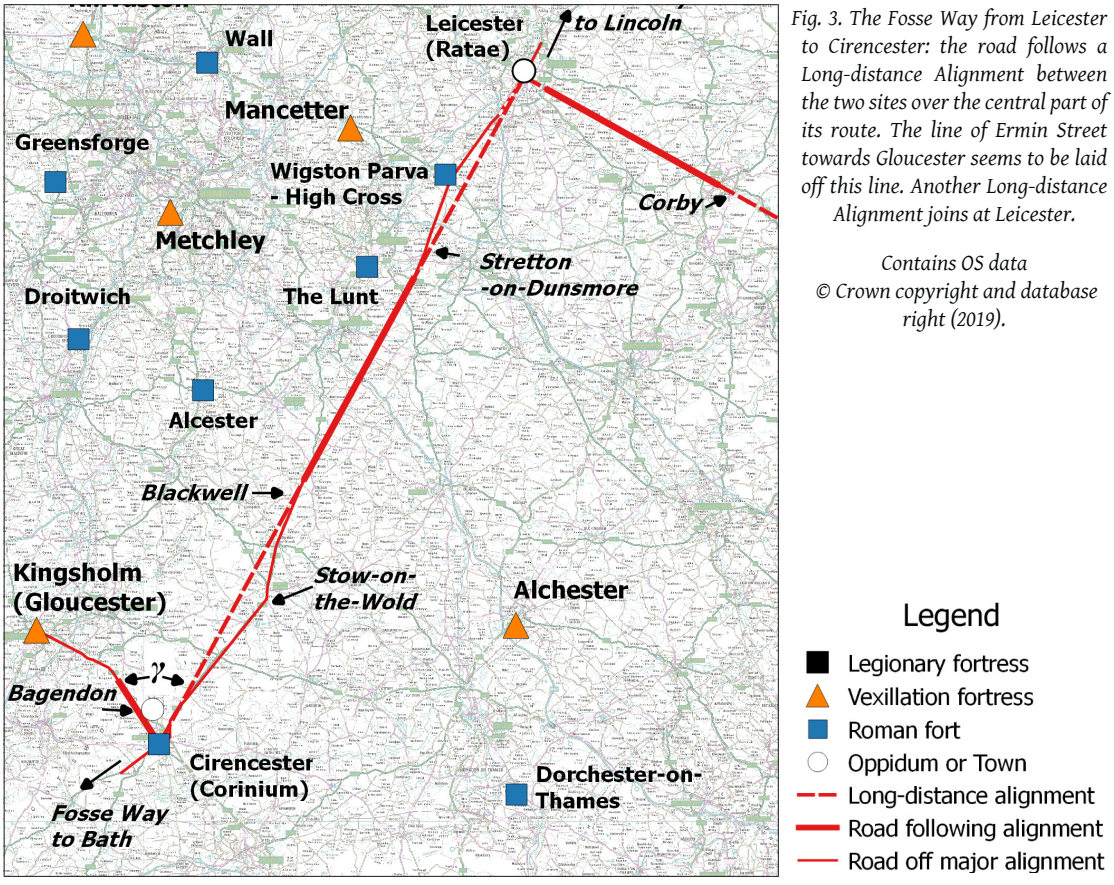


Fig. 3. The Fosse Way from Leicester to Cirencester: the road follows a Long-distance Alignment between the two sites over the central part of its route. The line of Ermin Street towards Gloucester seems to be laid off this line. Another Long-distance Alignment joins at Leicester.

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The existence of Long-distance Alignments has not been seriously challenged, but they remain a ghostly presence on the map. They are revealed by roads using their guidance, but road deviations often obscure the underlying planning. The Fosse Way between Leicester and Cirencester is a good example (Fig. 3). Its route is based upon a Long-distance Alignment which forms a direct line between the centres of the two locations: the central 34 km (21 miles) of this celebrated road is based upon that line. However, the Long-distance Alignment remained unsuspected as it was obscured by the road out of Leicester taking a diversion away from the line towards High Cross. A second diversion of the road towards Stowe-on-the-Wold, on the approach to Cirencester, was enough to hide the overall alignment, as at neither end does the road follow it.

A more complex example of a route underpinned by planning lines is Dere Street (Fig. 4), which likewise remained unsuspected until John Poulter made intensive study of the route. It came as a surprise to him to discover that the route was governed by a framework of alignments to which the road repeatedly returned (Poulter 2014, 8-10, 25-26).

Long-distance Alignments seem associated with an early phase of Roman activity in any given area. We see this in the focus of Long-distance Alignments on the Scotch Corner area, a location that was of greatest importance when the Brigantian state was allied to Rome, and when the nearby centre of Stanwick most likely formed the power base of Queen Cartimandua (Haselgrove 2016, 483; Entwistle

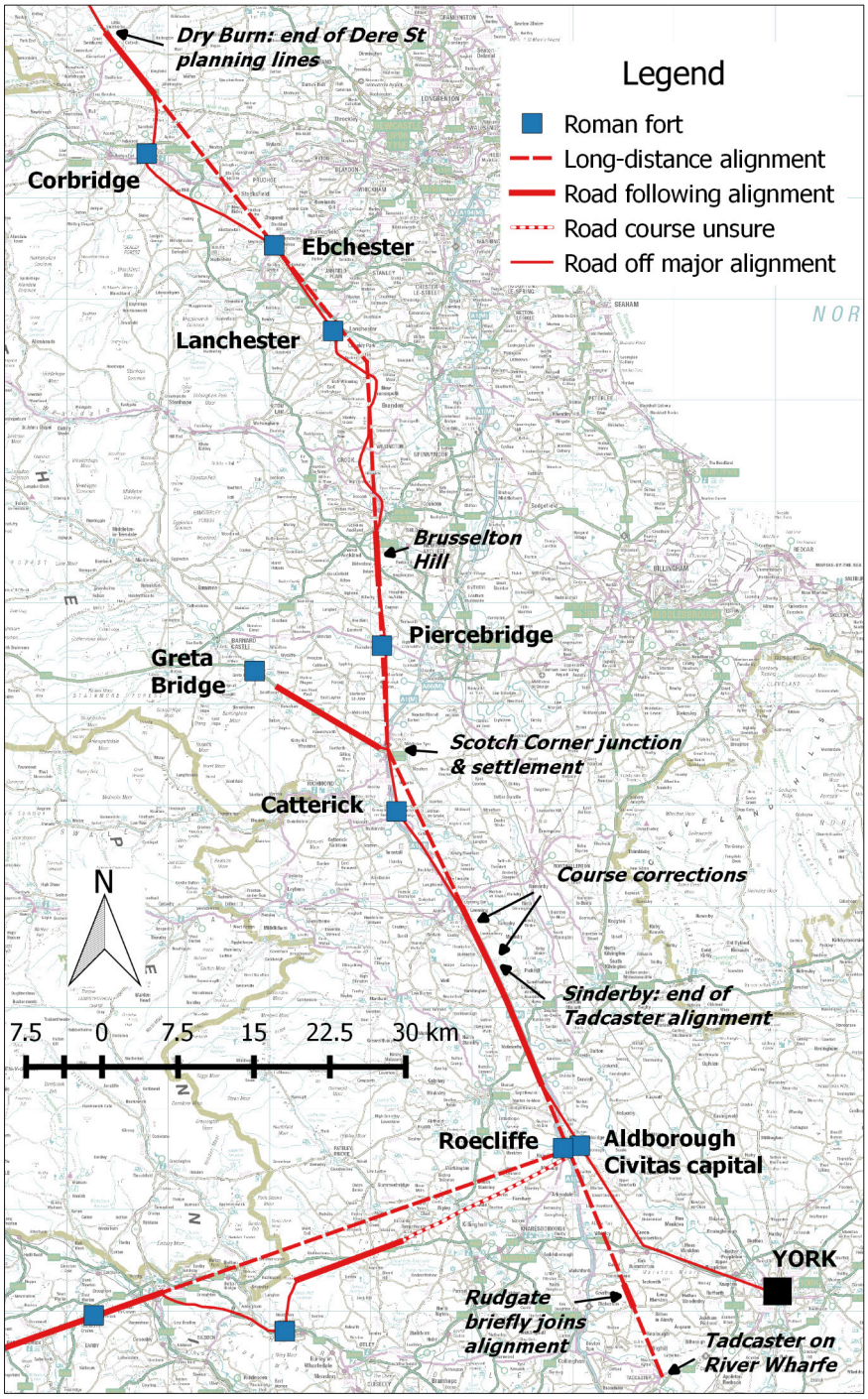


Fig. 4. Route of Dere Street, showing how its route is formed around a skeleton of Long-distance Alignments. Also shown, Long-distance Alignment marked by RR72a and RR720b west of Aldborough. Contains OS data Crown copyright and database right (2019).

2019, 86-88, 91-92). Similarly, Stane Street (Sussex) is best explained if we see the Alignment underlying it as laid out very early. It has perplexed many that Stane Street, emerging from London, was able to take a precisely direct line towards Chichester, 88 km (55 miles) distant over multiple horizons. The direct line between the two locations was clearly known before road construction started, as Margary acknowledged (Margary 1973, 64). Planning such a direct line between two distant existing locations would have been hugely difficult in Roman times, and unnecessary. Lewis analyses the issue authoritatively and concludes that establishing such a direct line would in theory have been achievable (Lewis 2001, 238-242), but only at the cost of enormous time and labour. If all that labour were intended merely to prepare a road route, then it would have been a remarkably pointless task: the road uses the direct line for less than one third of its length, and in any case would have been served just as well by an approximate line. By contrast, a Long-distance Alignment from the Thames crossing, at the earliest stage of conquest, could readily have been laid out towards the old 'Southern Kingdom', and used to define the location of the military base that ultimately evolved into Chichester. Ebchester, in the north, seems (as we have seen) to have had its location established on a Long-distance Alignment in just this way (Fig. 4). In the case of Chichester, an existing long-distance planning line would have eased the task of later road surveyors, who inevitably found themselves heading in the right direction just by using it (Entwistle 2019, 41-44).

Constraints upon Roman Surveyors

Long-distance Alignments commissioned from the *mensores* would have been a serious challenge to their skills but would have built on long-standing methods. Practice is best understood in comparison with modern surveying techniques, interpreted within the technical, conceptual and mathematical context of the age. Even before laser distance measurement and GPS became the norm, modern surveyors have assumed access to the graduated magnetic compass and optical instruments such as the sextant and theodolite. It goes without saying that the Romans had none of these. Lodestone (naturally magnetised rock) had long been known for its ability to attract iron, with knowledge of it credited to Thales of Miletus in the 6th century BC but regarded as little more than a curiosity. In Europe there is no reference to the magnetised compass needle until the end of the 12th century AD, first described by the English theologian Alexander Neckham in *De Naturis Rerum* around 1190, then by Peregrinus in 1269 in his *Epistola de Magnete* (Keithley 1999, 2-3). A form of solar compass is described by both Vitruvius and Hyginus Gromaticus, but it was large and required bright sunlight and many hours (from morning to afternoon) to find West-East, and therefore the cardinal points (*De Architectura*, 1.6, 6; *De limitibus constituendis*). A portable circular sundial could have been used in the same way to limited levels of accuracy (Campbell 2000, 494). An additional source of inaccuracy for any form of solar compass is that the high point of the midday sun deviates slightly over the course of the year (Isler 2001,165); certainly, as a means of walking on a bearing it was entirely impractical.

The telescope is even later, being invented in the early 17th century. By 1608 a few individual examples of low power telescopes were appearing, but it was Galileo who realised the potential of the device, greatly increasing its power, and bringing it to public attention through his treatise *Siderius Nuncius* in 1610 (Koestler,1968, 368). The first theodolite (without lenses) was invented by the English mathematician Digges in the 16th century, being a simple compass mounted on a tripod with a sighting device. Telescopes were not integrated into them until the 18th century (Hewitt 2010, 22). The first truly precise instrument was the 'Great Theodolite' built by Jesse Ramsden for William Roy: three years in the making and used for the London/Paris triangulation of 1787 (Hewitt 2010, 80). All

this might lead us to assume that the principal divide between ancient and modern surveying lies in a revolution in observational accuracy, brought about by the development of instruments that could exploit optics and the magnetic compass, particularly from the late 17th century onwards.

However, there was another, possibly more fundamental distinction. Roman surveying instruments lacked any scale, graduation in degrees, or provision for the measurement of angles. Indeed, the *groma*, celebrated as it may be, is so limited in its function that it could do no more than create or extend alignments forwards, backwards, or at right-angles. Although the viewing cords can be rotated horizontally, there is no scale for measuring this. Working within this limitation was a distinct preference for Roman surveyors as the superior Greek *dioptra* was available, but unused in the western empire as far as is known. That more sophisticated instrument was more compact and allowed both horizontal and vertical movement ¬– although even this, for terrestrial surveying, was not scaled in degrees (Lewis 2001, 100). That practice was reserved for astronomy: for scientific rather than everyday usage. The idea of dividing a circle into 360 degrees was ancient even in the Roman era, extending back to Babylonian times, yet there is no trace of that system being used in everyday Roman life. Measuring angles was not part of what Greek and Roman terrestrial surveyors conceived surveying to be about, and nothing suggests that they saw that lack as an inconvenience: had they desired it, the technology was available. In the modern world the measurement and determination of the angles and sides of geometrical figures are indissolubly linked, taught from primary school onwards, and constituting a fundamental part of surveying. In the Greek and Roman approach to geometry, however, the determination of angles was ignored entirely. Understanding that mindset is crucial to our appreciation of Roman surveying, avoiding facile comparison with modern practice.

A Rectilinear Approach to Surveying

It could be argued that Roman surveying practice was, at its core, about subjecting the environment to the service of the state by controlling and organising it through regimented systems of straight lines. Regulation of this sort could be used for town grids, centuriation (that is grid forms of agricultural holdings and access tracks), administrative boundaries, military camps, and roads. There were key advantages in such use of straight lines: structures became easy to plan, measure, and record. It also introduced predictability, allowing troops to move rapidly and efficiently to their quarters in temporary camps during a campaign, a point emphasised by Polybius (6, 41). For camps and forts, alignments provided the external outline, the positions of the gates, and the footprint of internal structures such as roads, barracks and granaries. Buildings were marked out in strips, each allocated a function, 'so that the whole system of surveying (*totius metationis*) does not fall into disorder' (*De Munitionibus*, 40). Used with skill, the *groma* was entirely appropriate for such work, providing users with the means to set out lines, extend existing ones, and turn at right-angles.

This surveying approach was so deeply ingrained that it became adopted for roads, the sinews of empire, even though their requirements were inevitably different. Roads could not be endlessly ruler-straight as routes must negotiate hills, valleys, bays, rivers and marshes; nevertheless surveyors brought the same skills to their planning. Lucilius makes casual reference to the use of the *groma* on the roads in his Satires (2nd century BC), turning the word (*groma* or *gruma*) into the unusual verb *degrumare: 'Viamque degrumavisti ut castris mensor facit olim'*: "you have 'gromered' the road as a surveyor does a camp" (Lucilius, Book 3, 96-7). The Roman habit of setting out roads in a series of straight alignments with little use of curves is so distinctive (and celebrated) a feature that it forms a

major diagnostic means of attributing roads to the period. The habit of forming routes from a series of connected alignments was simply the go-to professional solution for surveyors schooled in the Roman tradition. In a different era, a related mindset – aesthetic rather than technical – would impose structure upon nature through the disciplined avenues and formal gardens of Versailles, rather than the sweeps and romantic lakes of Capability Brown.

Triangles and Circles

Despite this preference for straight lines and rectilinear grids, the best trained surveyors would have been thoroughly familiar with, and able to use, wider aspects of classical geometry – which was the most developed form of mathematics in the Graeco-Roman world. The concept of 'similar triangles' was exploited militarily for such matters as finding the height of a city wall (Vegetius, *Epitome IV*, 30) or the width of a river when direct measurement in the presence of an enemy would be highly dangerous. In this latter case, surveyors would sight a virtual right-angled triangle over the water, then draw out a similar one safely on shore where distances could be measured without difficulty (Fig. 5).

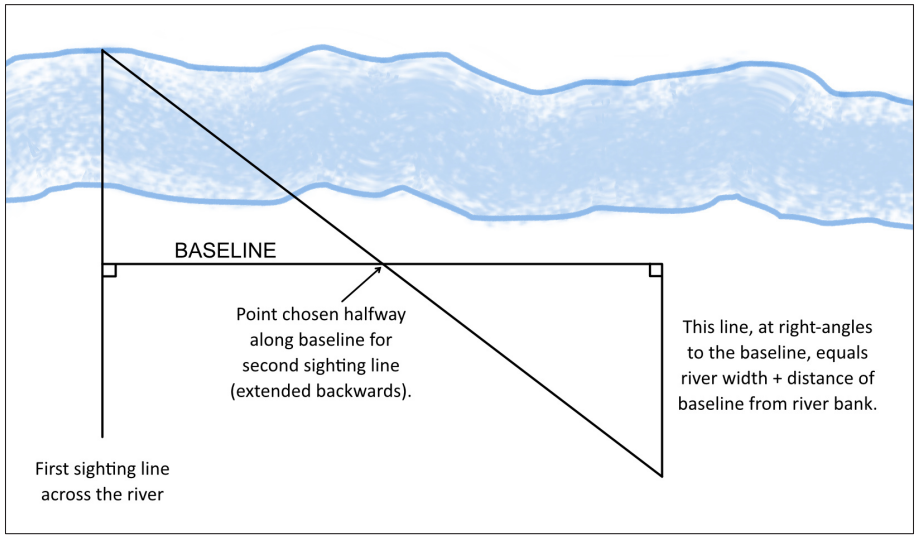


Fig. 5. Nipsus' method for measuring the width of a river using similar triangles.

This expertise with triangles, however, did not extend to the measurement or calculation of their angles (as discussed above), only the length and relationships of the sides and the calculation of area, and the ability to copy size and shape from one triangle to another through an understanding of 'similar triangles'. Even right-angles, fundamental to Roman surveying, were not considered as '90 degrees' but as the quarter of a circle. Pythagoras in the sixth century BC, who built an entire philosophy around geometry, produced his famous theorem regarding the length of the hypotenuse with no reference to angles, remarkable though that is to our conception of things.

The grounding of Roman surveyors in Greek geometry can also be seen in their ability to manipulate and exploit arcs of circles. This knowledge was exploited to establish the trademark 'playing card' rounded corners of camps and forts, each laid out as a quarter of a circle (*De Munitionibus*, 54). In construction, the iconic Roman arch, used in every large structure from triumphal arches to aqueducts and the Colosseum, was based upon the semi-circle – a concept further developed into the barrel vault (much used in baths). Most elaborately the concept became thoroughly three dimensional as the dome, seen to remarkable effect in the circular Pantheon in Rome, a major prestige project which still impresses today, and whose dome is (internally) a hemisphere. This extraordinary engineering project possessed sophisticated mathematical proportions, all based upon the circle (Fletcher 2019, 329-345).

Deducing Practice

Understanding the parameters within which the *mensores* operated allows us better to appreciate the methods available, and unavailable, to them in areas where practice is poorly documented – such as Long-distance Alignments. Their skills and understanding provided areas of strength, and areas of constraint.

It has sometimes been suggested, for example, that triangles being a fundamental aspect of Greek mathematics, the principle of triangulation could potentially have been used by Roman surveyors for survey work and mapmaking. Certainly, Heron of Alexandra had advocated the use of triangles for calculating land area (*Metrica*), and Moreno Gallo has demonstrated the sophistication with which this could be done (Moreno Gallo 2006, 39). However, triangulation as a means of topographical surveying, as against calculation of land area, was unknown in classical times. It is a superficially attractive idea to suppose that the *mensores* might have been early adopters of the methods developed in Europe from the 16th century, and which underpinned the mapping of Great Britain from the 18th to 20th centuries, but that process was not accessible to them.

The methodology of triangulation requires quite different skills and approaches from those of the Greek geometers. Whereas Heron divided plots of land into triangles and worked out their areas, triangulation as understood today does far more, accurately transferring an entire landscape to map form. It depends on laying out an expanding range of varied but juxtaposed triangles, growing away from a single baseline. That precisely measured baseline, through trigonometry, is used to calculate all other distances for the entire extent of the survey. For this to be possible, every triangle must have its angles precisely measured as it is laid out, requiring a theodolite or similar optical instrument capable of measuring in fractions of a degree. The process is expanded and continued until a designated territory is mapped.

Such a form of surveying was quite beyond Roman surveyors, skilled as they were: it depends on the repeated accurate measurement of observed angles, and consequent calculations. The *groma*, as we have seen, could not begin to do this observational work, having no capacity to measure angles. Triangulation was a process alien to the way Roman surveyors went about their craft, and they were not equipped for it.

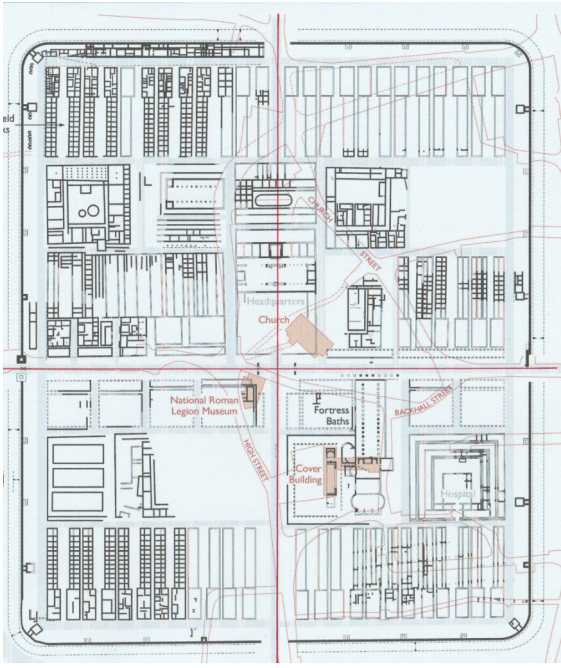
Long-distance Alignments and the Principles of Surveying

In investigating how Long-distance Alignments were surveyed, modern methods provide some indication of what is possible. The remarkably steady way in which Long-distance Alignments hold accurately to their course, and the precision with which turns are made, suggests that they result from practised methods, rigorously carried out. Authoritative guidance on comparative modern methods is drawn principally from *Surveying* (Punmia et al. 2005) and T*he Principles of Surveying* (Herubin 1974).

1: Precision and accuracy

In modern practice, precision is considered vital at every stage of observation, measurement and recording. Although absolute accuracy is unattainable, it should always be sufficient for the specified task, taking account of time and resources. Factors such as surveying methods, estimations, instrumental tolerances, and prevailing weather conditions all impact upon results. The same factors would have affected professional Roman surveyors; the instruments of that era had coarser tolerances, but precise handling could bring surprisingly good results. The principal operational weakness of the *groma*, other than lack of optics and graduated scale, was the thickness of the sighting cords (the nearer appearing broader than the further) and their tendency to swing in the wind. An experienced user could attempt to compensate for these failings, while attempting to ensure that mistakes or carelessness did not lead to further error.

Modern surveying emphasises the importance of rigour in observational practice: exact positioning and levelling of instruments, precision in observations, and repetition in case of doubt (Herubin 1974,



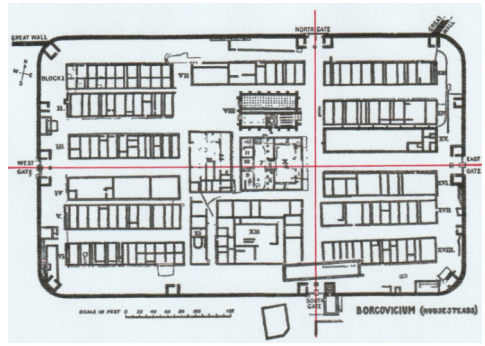


Fig. 6. Above. Housesteads Fort: squarely laid out, with the partial exception of blocks XVII and XVIII (Encyclopaedia Britannica, 1911). Most Wall forts show sound standards of layout.

Fig. 7. Left. The fortress of Caerleon (South Wales): competently and squarely laid out. (© Hawlfraint y Goron / © Crown copyright (2024) Cymru Wales.)

Note: Figs 6 to 9 are not to the same scale.

24-25). Within the technological limitations of the period, the best Roman surveyors would have concurred: Hyginus Gromaticus was disdainful of poor practice that used the *groma* insufficiently and left mistakes unrectified (*De Limitibus Constituendis* 154.18 – 155.7); Nipsus specified the precise setting up of the instrument, centring it over existing boundary markers and levelling it by use of a plumbline (*Limitis Repositio 7-18*).

Nevertheless, not all Roman practice appears quite so professional and conscientious. It is not rare for archaeologists to find examples of corners in Roman buildings, *insula* blocks in towns, and other planned structures, that are less than fully square – and military architecture is no exception, as Collingwood and Richmond noted: 'Normally a *castellum* is rectangular or approximately so, though its intended right angles are sometimes inaccurate' (Collingwood and Richmond, 1971, 26). Some military construction is, however, exemplary: legionary fortresses generally display competence in their design, exuding an impression of efficient purpose. Their footprint is well laid out: good parallel sides, well aligned internal roads, and buildings which are properly square.

Such well executed plans lead us to suspect the hand of trained and experienced surveyors, reflecting the assertion of Taruttienus Paternus that *mensores* were classed as *immunes* ¬– specialist military personnel freed up from duties affecting other soldiers (*Digest of Justinian* 50, 6, 6).

Some auxiliary forts, no less than fortresses, similarly display professional standards of layout. These include most examples from Hadrian's Wall, such as Housesteads (Fig. 6). It may be no accident, however, that Wall forts, like the Wall itself, are believed to have been built by detachments from the legions.

Forts, however, are more variable than fortresses in the competence of their design. Some, such as Gelligaer (Fig. 8) show less competence in their layout even though all the usual structures are present. It may well be relevant that some of these are strongly suspected of being built by the same auxiliaries who manned them. Auxiliaries must often have had to construct their forts without access

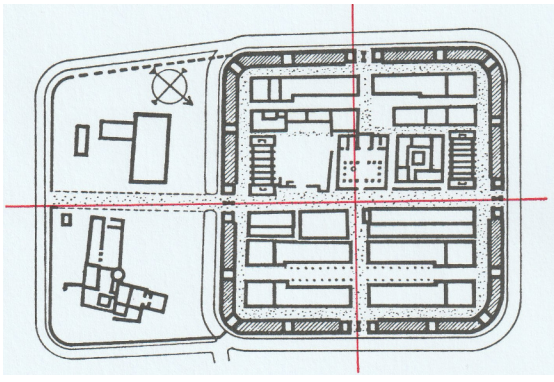


Fig. 8. Above. Gelligaer fort (after Nash-Williams). No doubt sound construction, but less expert in terms of layout.

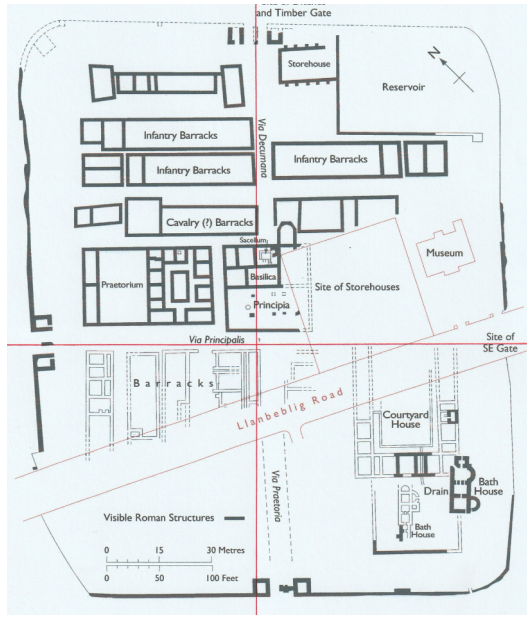


Fig 9. Right. Segontium fort. North Wales. Overlooking the Menai Straits, this fort, like Gelligaer, is less expert in terms of layout. (© Hawlfraint y Goron / © Crown copyright (2024) Cymru Wales.)

to legionary expertise: structures can be found where soldiers practised their fort-building skills – often small, but with particular emphasis on corners and gates. In Wales at least 18 such structures exist on Llandrindod Common close to Castell Collen auxiliary fort, and others are found near Tomen-y-Mur fort. For troops working without legionary supervision, ensuring that a structure was militarily sound, practical and secure would understandably have been a higher priority than overmuch concern for square corners and parallel sides. Where precision and accuracy of layout is evident, this should be considered potentially indicative of a trained *mensor's* input and possibly of legionary construction.

Roads, no less than forts, in general display practicality and solidity of construction, but variation in associated surveying standards. This is particularly evident where roads are preceded in their course by Long-distance Alignments.

Thus Dere Street (Fig. 4), in its different phases, demonstrates some of the best, and the worst, of surveying standards. Poulter demonstrates how the road's route was refined from a small number of Long-distance Alignments to a more complex practical cross-country route, the first and last phases sometimes separated by decades. In terms of surveying the first planning phase was far more expert than the construction phase, implying the involvement of separate teams: 'In contrast to this accuracy in long-distance surveying, the shorter distance planning of Dere street... shows evidence of mistakes'. Poulter identifies such a mistake at Bedale Beck, where connecting alignments are laid out poorly and fail to make an accurate junction with each other. 'This inaccuracy may reflect lesser skills amongst those surveyors who planned the road compared with those who set out the long-distance alignments' (Poulter 2009, 24). We may suspect that the initial Long-distance Alignments, presumably set out for strategic reasons, were surveyed by legionary *mensores*, whereas the final stage of construction used whatever surveyors were attached to the construction team, who may have been civilians (Moreno 2024, 61-62).

A similar impression emerges from study of RR150 in its crossing of the Weald, south of London (Entwistle 2019, 36, 38-39). The road moves between two different Long-distance Alignments, leaving Stane Street (on the Chichester alignment) in the region of Kennington Common (Margary 1973, 62) to navigate its way independently through modern Croydon and Godstone. Near Lingfield it attempts to swing on to the second Long-distance Alignment (Fig. 10) which crosses the Weald from the North Downs to Hassocks (where there is a Roman cemetery). By following this Alignment the road ends up running parallel to RR14 – obvious from the OS map of Roman Britain – which is following another linked Long-distance Alignment across the Weald (Entwistle 2023, 89). The road builders clearly intended to follow the line through to Hassocks and made a sharp turn toward it at 'Green Wood' (Fig. 10), where Margary notes a 'distinct change of direction to the south-west' (Margary 1973, 63). At Green Wood, however, they had already overshot the Alignment by some 0.7km, as perhaps they realised as they cut back quite sharply. They regained the line just west of Felbridge, but again, overshot slightly, suggesting that it was not clearly marked, except perhaps at high points. Two slight course adjustments brought them exactly to the Long-distance Alignment at Selsfield Common, the highest point of the Long-distance Alignment crossing the Weald, where we can expect there to have been a prominent marker. Beyond this point they follow its line approximately all the way to Hassocks, but consistently strayed a little eastward except where they crossed the valley now occupied by Ardingly Reservoir (not marked on the 1947 base map, Fig. 10). A late correction is finally made in approaching Hassocks (and the 'Greensands Way', RR140), where Margary again notes a turn (Margary 1973, 64).

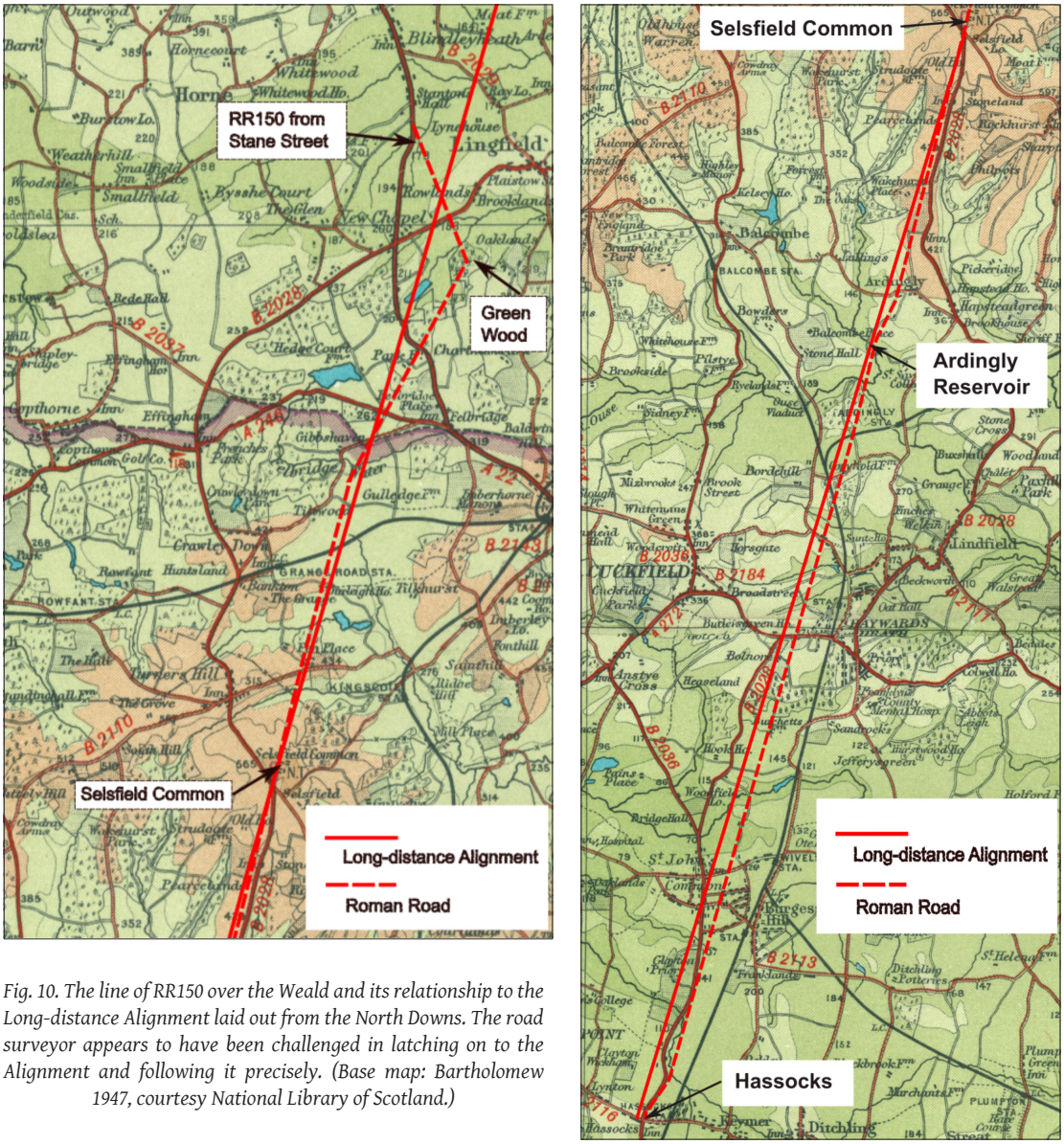


Fig. 10. The line of RR150 over the Weald and its relationship to the Long-distance Alignment laid out from the North Downs. The road surveyor appears to have been challenged in latching on to the Alignment and following it precisely. (Base map: Bartholomew 1947, courtesy National Library of Scotland.)

It is hard to believe that the surveyor responsible for setting out this road line was operating any significant distance ahead of the workforce, or surely directional errors would have been ironed out to reduce wastage of time and materials. His construction brief seems to have required him to plot the route in reference to existing Long-distance Alignments, which ought to have been straightforward, but no doubt proved a challenge through the hilly, wooded terrain, with limited numbers of markers. The result was solid and functional, fulfilling its design brief, but showing lesser surveying skills than those displayed by the original military team.

For both forts and roads, we can identify variable standards, gaining the impression that precision in surveying matters depended on both the task and the team: different tasks employed differently

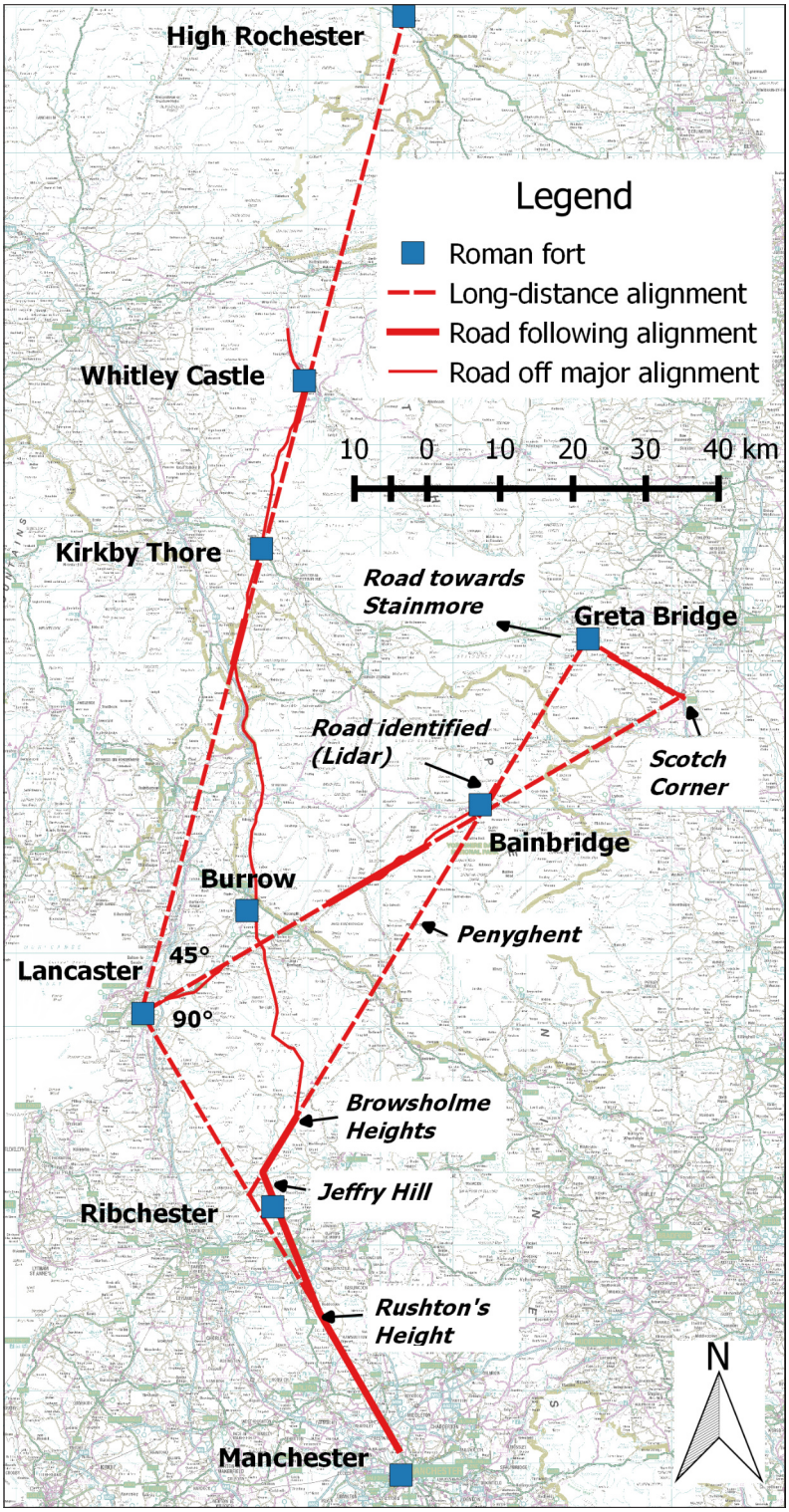


Fig.11. RR7c, travelling northward, swings sharply on to a Long-distance Alignment (LDA) at Jeffry Hill and follows it as far as Browsholme Heights. RR732 (marked 'Road Identified') follows the same LDA at a later point. The LDA is part of a group based upon Lancaster and Scotch Corner. See also Fig. 14

trained personnel, some being highly skilled, some less so. Long-distance Alignments show Roman practice at its most precise, powerfully indicative of professional legionary involvement. The methods they chose to employ remain to be examined.

2: Surveying a straight line

The most evident feature of Long-distance Alignments is the precise maintenance of a given alignment, possibly over scores of kilometres. We find this, for example, in the alignment laid out between Jeffry Hill (where the Western Main Roman Road, RR 7c, climbs to the hills above Ribchester) and the site of Greta Bridge fort (just east of the Pennines), two points separated by Penyghent, the Pennines, and 85 km (53 miles) (Entwistle 2019, 20-23). It would be difficult, perhaps, to find a more challenging line to survey, yet two different roads closely follow it, one well west and one well east of Penyghent, witnessing to the precision of the line (Fig. 11) The Main Roman Road swings dramatically on to this line on the top of Jeffry Hill (see also Fig. 14) in a turn of a little over 53 degrees, then off it again 8 km further on at Browsholme Heights. The second road to follow the line has only recently been discovered, far to the east of the first. Now labelled RR732, it climbs the fell above Askrigg, perhaps leading from Bainbridge to Bowes (Entwistle 2019, 22-23).

This sort of precision over long distances can be seen elsewhere. Stane Street (RR15), discussed above, is a celebrated example, in its alignment running southwest from London Bridge, over hills and ridges, directly to Chichester. The road itself follows the original Alignment only as far as Ewell (preserved as the modern road in many places), but the line, projected onwards, reaches to Chichester. The ability of Roman surveyors to maintain a straight alignment over score of kilometres is not a matter of dispute.

However, as has been demonstrated, in laying out precise alignments, the *mensores* were playing to their strengths. Rectilinear surveying – accurate prolongation of a surveyed line – was their fundamental skill. *De Arte Mensoria*, attributed to Frontinus, describes how the job was normally done: first checking the verticality of the *groma* by plumbline, then taking a backsight on earlier markers across a pair of cords. 'We first use the *ferramentum* [*groma*] and regulate all procedures by plumb-line... then sight the markers and take a back sight on them'. He continued to show that once the cords were aligned and set, they were used as a foresight to position new markers ahead. In due course the instrument moved forward to these, and the process was repeated (*De Arte Mensoria* 16.6 – 17.9, translated Lewis 2001, 325).

The process of *chain surveying* is the nearest modern equivalent to the Roman process, carried out using linear measurements only (i.e. no theodolite or compass). The handbook *Land Surveying* describes this process as 'The earliest form of surveying', nowadays used only for small surveys (Wilson 1977, 33).

An alignment projected forwards is, in modern surveying parlance, a *traverse*. Punmia's description of its creation through the process of *chain surveying* is very reminiscent of Frontinus. At a chosen spot, Point *A*, the surveyor ensures that his instrument is set vertically and horizontally to avoid introduction of error, then sights forward with it to establish Point *B*, and moves forward to that point. From here he takes a backsight to *A*, to ensure continued accuracy of the line, and clamps his instrument to avoid it being nudged out of true when he changes direction. He then shifts the viewer 180 degrees and takes a foresight to establish *C*, the next point on the *traverse*. In due course the surveyor moves to *C*, takes a backsight to *B* and continues onward as necessary (Punmia et al. 2005, 153).

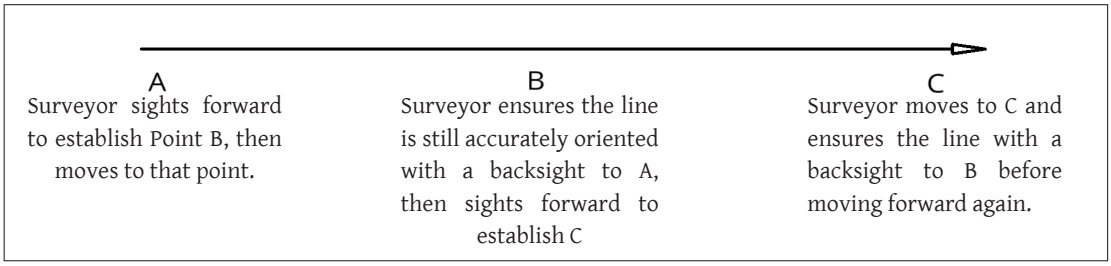


Fig. 12. Sighting a traverse.

The backsight, mentioned by Frontinus, deserves particular emphasis; in Herubin's view, taking a long, accurate backsight and ensuring that the sighting starts from a sound basis, is even more important than the foresight in limiting error (Herubin 1974, 116). In essence the whole sighting process is much the same as in Roman times: a *mensor* would feel at home taking part in it.

Surveying through means of a *traverse*, is regarded as a rapid and effective way of localising and recording points of interest (whether natural or man-made) relatively close to the line. The location of each such point is identified in relation to the line of the *traverse*, for example by laying out an *offset* towards it, and duly recording it as part of the survey (Punmia et al. 2005, 165). We might expect that the Romans would similarly wish to record points of strategic importance as they progressed. Field notes are a closely controlled part of surveying today (Punmia et al. 2005, 23) and the *mensores* would surely be aware that a survey's value would be much reduced without observations made on the spot.

Chain Surveying is not usually used over long distances, but the *mensores* would need to have found ways of making this sort of process work efficiently over tens or scores of kilometres of difficult ground, without optical aids and ideally avoiding hundreds of short observational hops.

Working from whole to part

One means of preventing the accumulation of small errors in surveying is considered fundamental today. Punmia states that a 'ruling principle of surveying... is to work from whole to part. It is very essential to establish first a system of control points and to fix them with higher precision. Minor control points can then be established by less precise methods' (Punmia et al. 2005, 3). Herubin similarly points out that the longer the distance over which a sighting is taken the less opportunity there will be for error, and 'this applies until extreme range reduces visibility because of limitations...of the person's eyes' (Herubin 1974, 116).

We have good evidence that Roman surveyors acted on these principles in their works, even though there is nothing concerning it in the literary record.

What was seen (at the time) as 'the longest straight alignment of the ancient world' (Lewis 2001, 242) is the line of the outermost Upper German-Raetian limes which stretches almost ruler-straight for 81.3 km between Haghof in the south and Honehaus in the north, with only a single (1.6 km) deviation to avoid a steep valley (Fig. 13). This was laid out, presumably by legionary *mensores* c AD 160, and was formed of a palisade, ditch and bank with irregularly spaced stone watch towers. A precise modern survey of the southern 29 km shows that the mean deviation of the ditch from a truly straight line was plus or minus 1.9 m, with an almost equal directness maintained further north. Lewis argues that

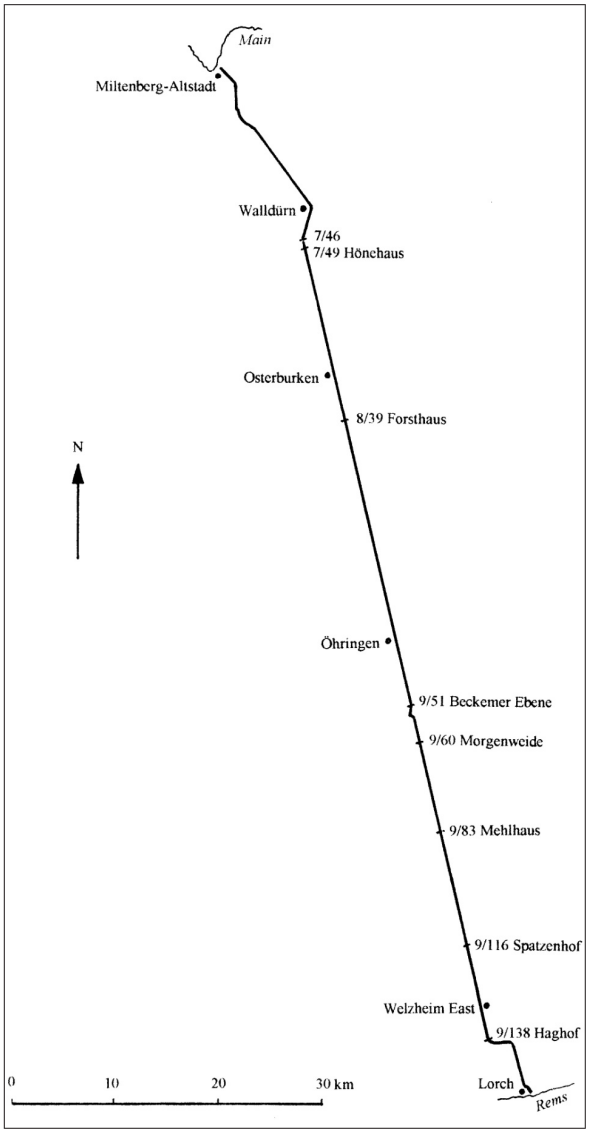


Fig.13. The Outermost Upper German-Raetian limes*. The line was laid out almost ruler-straight from Haghof to Honehaus, demonstrating the practice of forming long observational leaps, later divided by interpolation. (Diagram courtesy Michael Lewis.)*

the whole system was surveyed by sighted alignments, using the longest observational hops possible. He considers that six were likely between Haghof and Honehaus, the longest being between Forsthaus and Honehaus (around 17 km.). Once those sighted leaps had secured the accuracy of the whole line, intermediate markers for the construction teams were backfilled by 'interpolation', with noticeably less accuracy. Thus, it seems that once the critical overall accuracy of the survey had been secured with long sightings between key points, smaller intermediate divisions were regarded as less critical. The whole was more than the sum of its parts.

We are reminded of the way in which individual stretches of road alignment often follow a Long-distance Alignment somewhat approximately, as in the Weald (Fig. 10). During road construction, attention to an exact line was of little consequence providing that it could continue to be used as a guide. Road surveyors had different priorities from the *mensores* who laid out the Long-distance Alignments.

We can recognise the same strategy in other works of Roman surveying. The great marble map of Rome, the *Forma Urbis Romae*, reflects the city as it was in the early 3rd century. Only fragments remain, but it must have once been over 18m long. Analysis suggests that the major parts of the city were carefully set out to scale, but representations of buildings and other details were fitted in less accurately once the overall picture was established. Accuracy of the whole was of greater consequence than accuracy of the parts (Lewis 2001, 100).

We can find a final probable example of this practice in the alignment (already referred to) leading to Jeffry Hill, near Ribchester on the Western Main Roman Road (Fig. 14). Close to Whittlestone Head, the road heading north from Manchester turns off its existing alignment to head directly for Jeffry Hill, 20 km (13 miles) away. First it must climb to the Top of Ramsgreave, 11 km (7 miles) away, then dip down into the Ribble Valley and across the river past Ribchester, before climbing to Jeffry Hill.

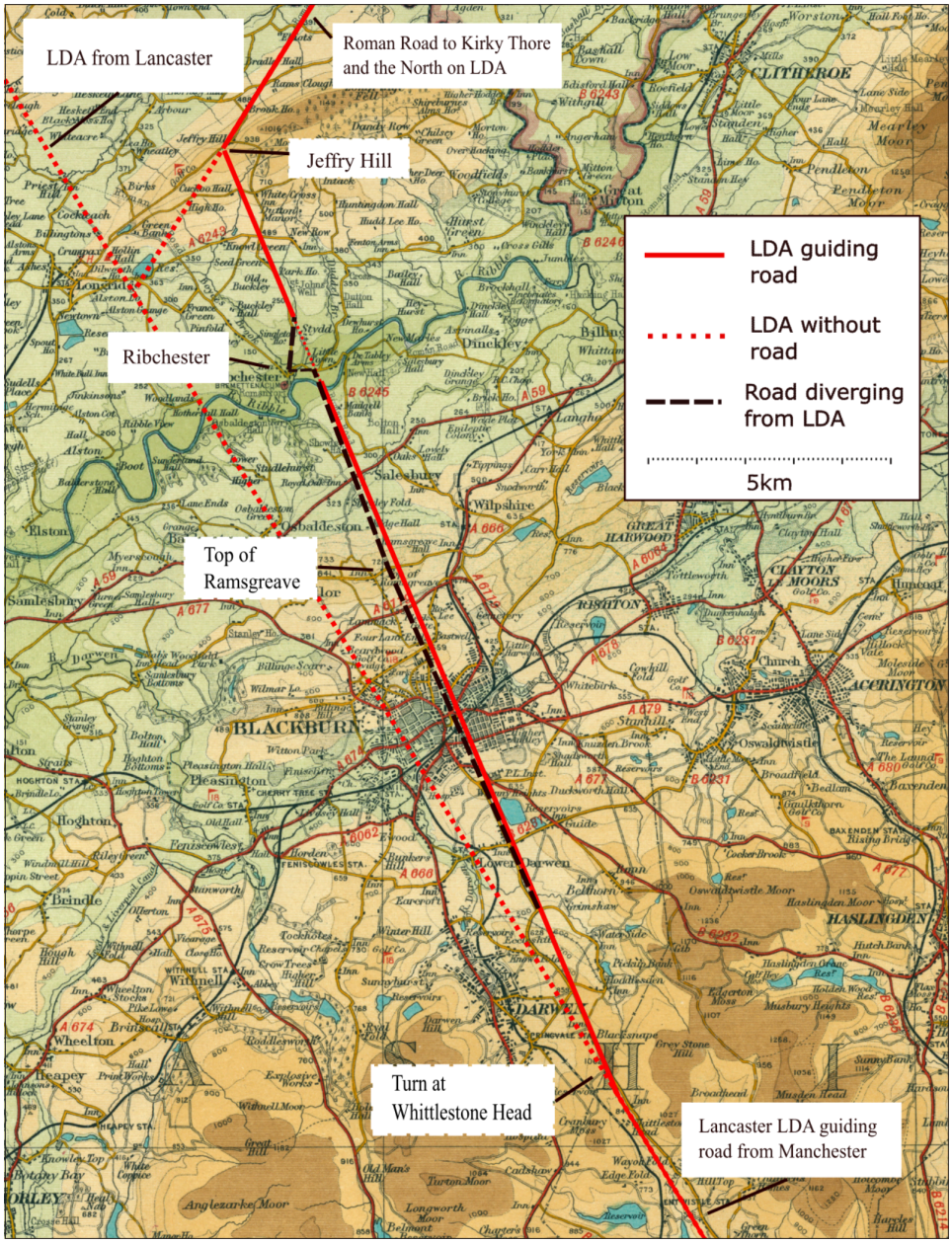


Fig 14: The alignment between Whittlestone Head and Jeffry Hill is more precise than the two subsidiary alignments from Whittlestone Head to Top of Ramsgreave, and Top of Ramsgreave to Jeffry Hill, which diverge 120 metres off-line. (Base map: Bartholomew 1947, courtesy National Library of Scotland.)

The Long-distance Alignment between Rushton's Height and Jeffry Hill extends nearly 21 km (13 miles) but would appear to have been set out in a single leap. At the Top of Ramsgreave, the intermediate high ground, we find that the road has shifted some 120 metres off-line, necessitating a

minor correction towards Jeffry Hill. This may well be a case of a single long alignment being subdivided less accurately for the purposes of road construction. The *mensores* had, with great precision, taken the largest leap available to them, leaving the Lancaster-Manchester line at a pre-formed angle (Entwistle 2019, 27). Once overall accuracy had been assured, precision over Top of Ramsgreave was not a key priority for road surveyors.

One major issue before the age of optics would be Herubin's warning that the benefits of long observational leaps for greater accuracy only work up to the point where 'extreme range reduces visibility'. We can assume that Roman surveyors would have been highly aware of this issue, although we can do little more than speculate on the means adopted to mitigate the problem. John Poulter (and others) have suggested the use of lights at night (Poulter 2014, 22), and this does indeed vastly increase the range over which a point can be viewed. However, without the means to establish a bearing in degrees, seeing the point is of little advantage, and a *groma* cannot be used in the dark. A likely alternative solution was to go for size and skyline location in setting a point intended to be visible from afar. We can make informed judgements about where some such points would have been positioned, but until we find post holes or other structural evidence, the matter must be left open. Roman engineers, we may be sure, would not have been deterred by such challenges.

Line-of-sight or Bearing

In the modern world, if an alignment is created there is a choice between laying it out by line-of-sight, or by compass bearing. Over a long distance, perhaps surprisingly, the two are not the same. Because of the curvature of the world, a compass bearing does not represent the shortest line between two points that are very far apart, but curves gently away from that line (finally spiralling to the poles) (Boas 1962, 205). On a Mercator-style map (which squashes the round earth on to a flat plane), by contrast, it is the compass bearing which is straight, and the line-of-sight (or 'geodesic' line) which should show a gentle curve.

As the magnetic compass was not available until many centuries after the Roman era, this paper has maintained that Long-distance Alignments would have been laid out by line-of-sight rather than by bearing. That, however, has been a subject of debate between the author and John Poulter, who has recently argued the opposite (Poulter 2024, 265) – one of the few points on which they have disagreed. Poulter argues that as Long-distance Alignments are not noticeably curved on maps, they must have been laid out by compass bearings rather than by 'line-of-sight', and that the Romans must have found a way of utilising lines of constant bearing, even though the magnetic compass was still to be invented.

There can be no argument with the principle of a geodesic line forming a gentle curve on a Mercator-style map, but Google Earth, which this author uses to trace longer alignments, already makes allowance for geodesic paths, leaving those observations unchanged. The extent to which a 'geodesic' line shows curvature over long distances on a Mercator-style map can be measured but varies between cases, depending upon latitude, distance, and direction. For a line running due north-south a geodesic line and a bearing are identical. The example used by Poulter is the line of the northern end of the Devil's Causeway (near Tweedmouth), extended to Scotch Corner. Just the first 16 km are indicated by the road and form the only part of any longer alignment that is guaranteed. The argument that it reached to (and was laid out from) Scotch Corner – 130 km directly ahead on the map – is persuasive but unproven, as it is not known to connect with any other Long-distance Alignments or pass through Roman sites.

Because a geodesic (line-of-sight) path following such a long course should be curved, it will follow different compass bearings at its northern and southern ends. Those can be calculated once start and end points are known, but in this case the difference turns out to be minimal: 171° 48' 36" and 172° 04' 25" respectively. With something like a mere quarter of a degree separating them, the curvature over 130 km is barely perceptible. The geodesic line (line-of-sight) turns out to agree well with the 16 km course of the Devil's Causeway near Tweedmouth, and the author sees no need to pursue other alternatives.

The curvature is nevertheless sufficient for a best-fit geodesic line based upon the northern section of the Devil's Causeway to by-pass Scotch Corner some 600 m to the west (having traversed the Stanwick complex). That might imply that the case for a Long-distance Alignment between Scotch Corner and Tweedmouth should be reviewed.

Roman error checking

An issue that we have not explored is the issue of Roman surveyors error-checking their own work. However carefully they went about matters there is always the possibility of error in a sighting, which if not corrected would become steadily more serious as the *traverse* began to diverge from the intended line. Hyginus Gromaticus was aware that errors made at key points in a survey could propagate larger errors, and that cross checks were important. Thus he commented (in discussing centuriation): 'The DM and KM must be plotted by very good surveyors, who must also fix the end of each *quintarius* (i.e. every 5th intersection), to prevent error which if accumulated will be difficult to correct. If there is a defect in the *groma* or the sighting, a wrong observation immediately appears on one *quintarius* and admits of fairly easy correction' (quoted Dilke 1971, 58).

Modern surveyors build in checks to try and prevent unplanned error in the first place, and to reveal it should it occur, so that it may be corrected. This is most easily done for a *closed traverse* (which links back to the beginning), where it is obvious if the *traverse* does not close upon its starting point, and where internal checks on the geometry of the loop are possible. It is much more difficult in an *open traverse* – and the checks suggested by Punmia require the measurement of angles (Punmia et al. 2005, 167).

The remarkable accuracy sustained by Long-distance Alignments over score of kilometres implies either that the Roman surveyors had such robust systems in place that mistakes were not made, or they had developed a means for correcting errors as they occurred. One possibility stands out, reflected in modern usage, although it would have greatly increased the surveying workload.

In 1967 the United States Coast and Geodetic Survey had the task of creating a precise straight line, some 35,600 feet long, for a high-speed sled track at an Air Force base in New Mexico. The basic work was carried out by triangulation, but as an accuracy check two parallel *offset* lines were also surveyed. For reasons relevant only to the site in New Mexico, the distances chosen were 80 and 100 feet from the main line. As the three lines were independently laid out, the accuracy of each could be readily confirmed by measuring distance from the other two at different points (Jones and McKay 1969, 398-401).

Johnston similarly suggested in 1979 that the Romans might have surveyed parallel lines as a means of roads by-passing obstacles (Johnston 1979, 69), and it is a strategy that would have paid off in terms of error-checking. Any errors in the establishment of a line would become clear if independently surveyed lines approached or separated. Whether this was really a strategy adopted cannot now be

proved: we might expect that 'steering' alignments would not be retained once their purpose was served. Nevertheless, we find roads following Long-distance Alignments sometimes moving to a closely parallel course for a stretch, and this represents one (but not the only) possible explanation for the phenomenon. Thus, the Western Main Roman Road (RR7b) north of Manchester is seemingly on-line as the A56 through Prestwich, and also at the Lowercroft reservoirs between Ainsworth and Walshaw (SD 7717 1096); yet a little further north through Affetside (SD 7558 1351) the line (represented by the modern road, named 'Watling Street') runs some 53 metres west of the Alignment for around 2.5 km. Roman roads, as we have seen, sometimes follow Long-distance Alignments a little haphazardly, but a closely parallel course seems to be something else. We also find examples of roads moving to a more distant parallel course, but these are likely to require other explanations. One such example, for which we have only tentative theories to date, is seen in Fig. 4, where the Long-distance Alignment approaching Aldborough from the west carrying roads RR72a and RR720b (possibly now to be considered as a single road) jumps over 3 km southward to follow a parallel course over Blubberhouses Moor.

3: Turns in alignments

A *traverse*, in modern surveying, has a beginning and an end; either it returns to its starting point after a series of turns (a *closed traverse*) or it ends at another point (an *open traverse*). Most Roman Long-distance Alignments that we observe form *open traverses*, with turns or branches (such as we have seen on Jeffry Hill) present in most. We can expect surveyors to have kept a careful record of where turns occurred.

An initially unexpected, but fundamental, finding regarding Long-distance Alignments relates to these turns. The same four angles are found to be used repeatedly in turns and branches: the angles present in two 'Pythagorean Triple' triangles, the 3:4:5 and the 8:15:17 (Fig. 15). Both triangles are not only right-angled but share the property (common to all 'Pythagorean Triples') of having their three sides measurable in whole units (i.e. no fractions or decimals). Although four angles may seem a very limited range for surveyors, they constitute 16 directions of travel in total when used right or left of an alignment going forwards, and right or left going backwards (Fig.16).

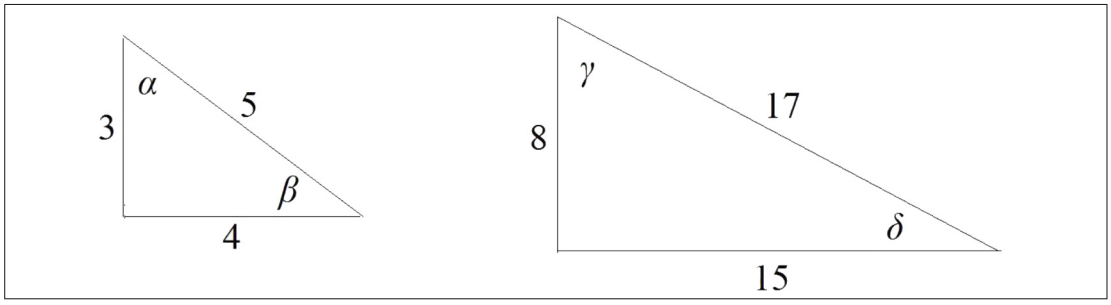


Fig. 15. The 2 triangles used in laying-off angles for Long-distance Alignments. All sides are measured in whole units.

Use of these triangles is not so strange as it might first appear. Pythagorean Triples were known as early as Babylonian times, but so far as this author is aware, only these two are mentioned in any context by Roman writers: the 3:4:5 by Vitruvius (*de Architectura X*, vi, 4), and the 8:15:17 by Marcus

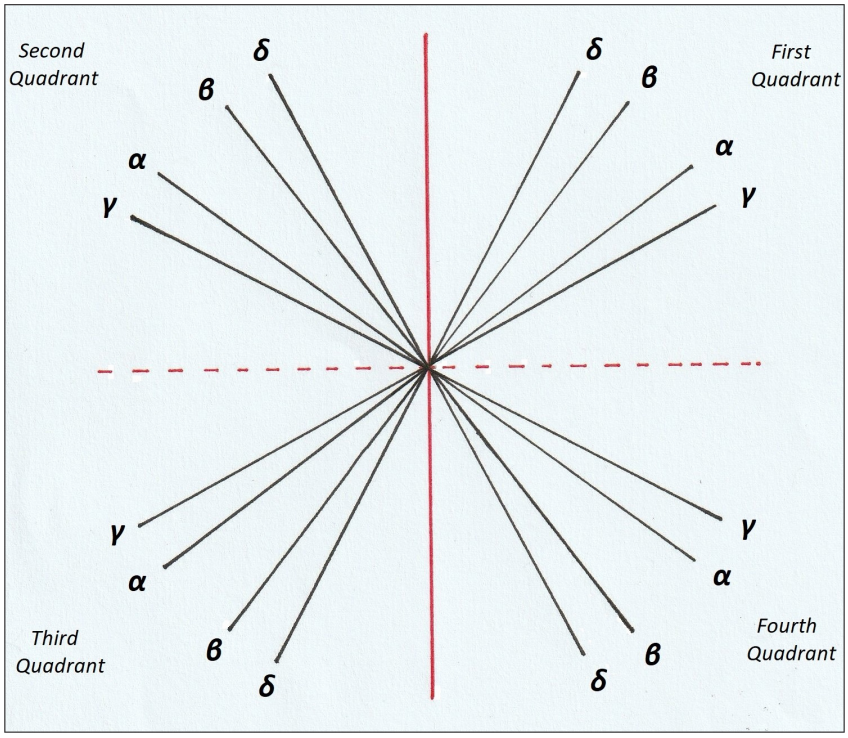


Fig .16. The pre-set angles used in laying off turns. Four angles, forming 16 directions.

Junius Nipsus (an *agrimensor*) in the *Corpus Agrimensorum*. He uses it in setting a mathematical problem (*Podismus*, quoted Dilke 1971, 55-56), where the whole units forming its sides ease calculation. He also uses the 15:20:25 'Triple' triangle in a similar way, but that is merely the 3:4:5 writ large (multiplied by 5).

These 3:4:5 and 8:15:17 triangles possess specific advantages which made them familiar and useful to surveyors. They are easy to measure out because their sides are composed of whole numbers; but they have the additional advantage (alone among the simpler 'Triples') that their 'vertical' sides can be drawn out as exactly one cubit while the other sides remain measurable in whole palms and digits – the standard Roman measurements of length (for more detail see Entwistle, 2019, 101-106). A reasonably skilled artisan could have produced precisely made portable rods, based on a cubit, that would form these triangles predictably and accurately.

All this, however, leaves aside the question of why standardised, pre-formed angles of turn should be found at all as an aspect of Long-distance Alignments. We must now turn to that.

Measurement of turns in degrees, the usual modern method, was not available to Roman surveyors. However, even in modern times, there is a system of surveying that manages without angles measured in degrees.

This is the *chain traverse* which is reliant upon linear measurement alone. Angles of turn, when required, are formed as chain angles, or tie angles, measured out by chain and tape (Punmia et al.

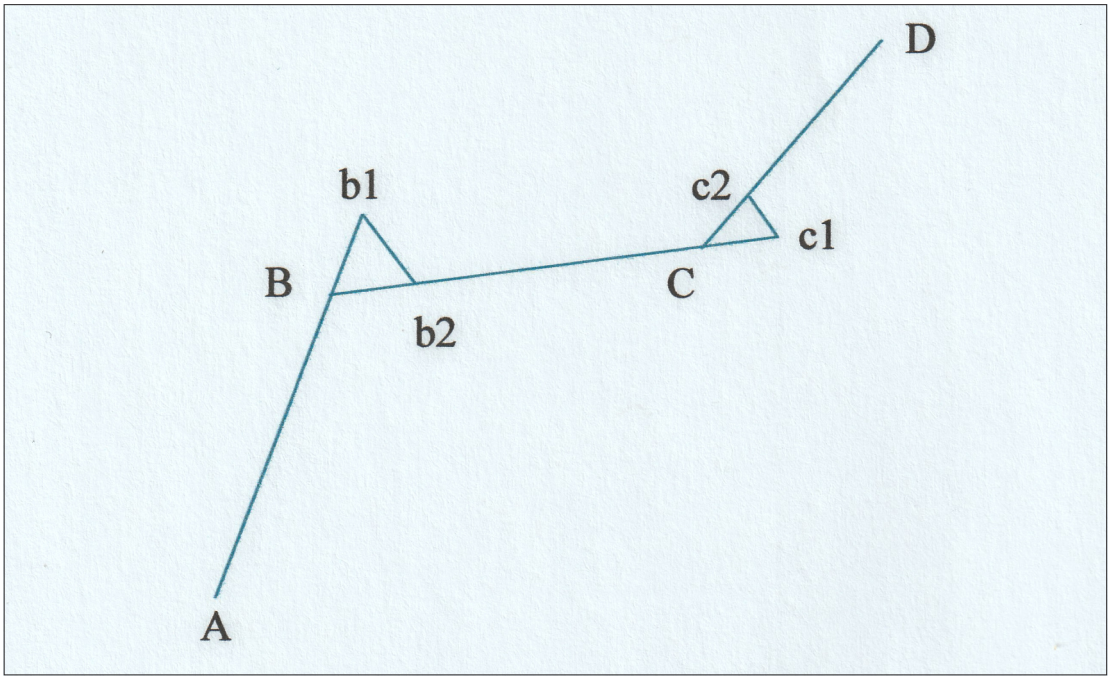


Fig. 17. The chain traverse (ABCD) has turns formed from linear measurements, as at B-b1, B-b2, and b1-b2.

2005,161). Three measurements of length form each angle, effectively creating a triangle with sides of known length at each point of turn, one side in line with the original direction of travel (backsight), a second in line with the new direction (foresight), and a measured tie line connecting the two (Fig. 17). This method was just as available to the Roman world as to the modern, but in the modern world it is regarded as 'unsuitable for accurate work' (Punmia et al. 2005,162), no doubt due to the potential for error in pegging out measured turns on uneven terrain in difficult conditions. Roman surveyors seem to have controlled this by using pre-formed, accurately measured triangles, which could be levelled and sighted (Entwistle 2019, 24-27).

In a modern *traverse*, a change of direction (whether of the main line, or to form a new subsidiary line) should take place at a *station*: a measured point along the *traverse* marked in a semi-permanent way, as by knocking a post into the ground (Punmia et al. 2005, 85). It is emphasised that for the deflection to be precise, an exact backsight must be taken on the existing line before a foresight is taken on the new line. This, we have seen, was the practice recorded by Frontinus before any new alignment.

Herubin, in discussing the modern *traverse*, advises on two ways in which an angle can be turned from the main line, whether to modify that line's direction or to lay out a subsidiary one. Either a convenient point is sighted and the angle measured directly towards it, or the angle is *laid off*. In the second case 'the angle is known ahead of time and the point is established at that angle from a given line' (Herubin 1974,112). The first option was not available in the Roman world as there was no means of measuring an observed angle; it was however entirely possible to *lay off* a pre-established angle from a given point on the line, as certain angles could be created by linear measurements. Indeed, this would bring about precisely the results that we repeatedly observe on Long-distance Alignments.

Roman angles, as we have seen, were not based upon degrees, but upon linear measurement. This could be done by measuring along the x-y axes of a right-angle, as described by Lewis (2001, 228). Peterson gives examples of something very similar with roads crossing a centuriation grid diagonally by counting off squares each way, cutting through the corners of the grid like a straight line through a graph (Peterson 1993, 98). The two right-angled triangles we have discussed (3:4:5 and 8:15:17) provided two angles each, formed in this familiar way, enabling Roman surveyors to plot, lay out, and record their turns (Fig. 16).

For Long-distance Alignments to have been set out with the precision we see, the *mensores* were clearly proceeding in a highly organised way. We can expect backsights to have been regularly taken on previous markers before foresights were taken to prolong existing lines or *lay off* new ones. A triangle could have been measured out afresh on the ground for each angle *laid off*, as in modern *chain surveying*, with the appropriate side serving for the foresight. This method would enable large triangles to have been laid out, increasing accuracy; however, it would also introduce the possibility of measurement error and require truly horizontal ground. This author favours the hypothesis that surveyors familiar with the *groma* and accustomed to sighting across plumblines at a convenient height, using a levelled instrument, might well have operated in similar fashion for *laying off* pre-set angles. A triangular frame made up of standardised rods with corner plumb lines, capable of rotating on a *groma* staff, would have permitted angles to be sighted in much the same way as a continued straight line.

Managing distance errors

Modern surveyors accept that error is inevitable and strive to manage it within limits appropriate to the task in hand, taking account of methods used, time and resources (angle 1974, 22). It is reasonable to ask whether the *mensores* had any similar conception of acceptable margins of error in their work, and how far they were aware of fundamental limits to accuracy that were implicit in their methods.

For Long-distance Alignments created by the methods discussed in this paper, the aspect most subject to intrinsic error (rather than human mistake) would have been measurement of distance. Alignments could be sighted, and angles *laid off* for turns, with some precision – but measurement of distance travelled over the length of a survey was more problematic.

Surveyors habitually used ten-foot rods for small-scale surveying tasks such as laying out camps: there is no record of them using anything longer such as cords or chains (Lewis 2001, 21). Clearly such rods could not be used to measure miles travelled along a *traverse*. On roads the best option would have been the hodometer, if available: this was a cart whose wheels drove cogs, enabling a stone to be dropped after each mile to mark the distance. We are given specifications of the machine by both Hero and by Vitruvius, with Vitruvius describing it as 'handed down by our predecessors' (*De Architectura, X*, 9). For roads it would have provided a reasonably exact means of measurement, but over rough ground it could not function, and the only alternative was pacing.

The Roman mile, 'mille passus', was a 'thousand paces', or 5000 Roman feet. The pace has remained a rough and ready way of measuring distance into modern times, and the professional 'bematists' or 'step measurers' who accompanied Alexander's Asian campaigns are credited with remarkable accuracy. Today it is considered that with practice, pacing can give an accuracy of 1 foot/metre in 100 (Herubin 1974, 39; Punmia et al. 2005, 38), although compensation is required for obstacles and slopes.

Pacing provides a valid way of judging distance but would have been considered quite inappropriate for tasks requiring high precision, such as centuriation. Roman surveyors will have understood that linear measurements in Long-distance Alignments, especially over hilly terrain, was the least accurate part of their work. Herubin views modern surveyors as having a duty to manage such issues: 'To control error so that the total error is not excessive, sources of error must be understood and methods and equipment must be chosen that will reduce the total errors to allowable limits' (Herubin 1974, 24). The remarkable precision by which the *mensores* maintained the line of their Long-distance Alignments, and the accuracy with which they *laid off* prepared angles, suggests that they were determined to maintain accuracy over aspects fully under their control. Knowing that there could be no absolute precision over distance travelled, this may reflect a concern to keep error in major surveys within understood limits.

Conclusion

We have associated Long-distance Alignments with an early phase of Roman activity when strategic needs were key and engineered roads not yet completed; and argued that to maintain accuracy they were laid out by line of sight using the largest leaps possible (and not by bearing). We have proposed that there was more in common between professional surveyors in ancient and modern times than is sometimes allowed, with certain strategies and approaches remaining relevant across the centuries. Not least important was preparation: Roman surveyors understood that precision in the positioning and setting up of their instruments was as important as precise observation. We have seen also, however, that standards varied between different classes of surveyors, and in certain building tasks the services of surveyors are unlikely to have been used at all. Where the work of legionary *mensores* can be strongly suspected, the degree of competence is usually high.

We have suggested that the greatest single distinction between ancient and modern surveying was the lack of any attempt in Roman times to measure angles in degrees, which immediately excludes Roman surveying from much recent practice, including modern conceptions of Triangulation. Consequently, the most relevant aspect of modern surveying to Roman practice, as we see it in Long-distance Alignments, is the minor branch known as *chain traversing*, using *chain angles*, which depend upon linear measurement only. Nevertheless, this form of surveying seems to have allowed ground to be covered rapidly, taking account of features of strategic interest. Corners were turned, and subsidiary lines laid out, utilising prepared angles in a way that is still recognised today. The resulting alignments, laid out in the field, had the advantage of being readily and accurately preserved through diagrams and records.

All surveying that operates over long distances has a high potential for error. It is hard to believe that Roman surveyors could have managed without systems of checks to ensure that Long-distance Alignments remained sufficiently accurate and reliable to be useful, hypothesising that this might have been done through projection of independently surveyed parallel lines. Roman surveyors would have been highly aware that their greatest source of approximation in producing reliable data lay in distance measurement, although there would have been a sound understanding of distance as marching time. By contrast the *mensores* kept a tight rein on those aspects of Long-distance Alignments which could be closely controlled: precision of alignment over great distances, and the accuracy of turns. These aspects still impress today.

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