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DOCTORAL THESIS

Organisation of Roman Iron production in the Weald

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I certify that all material in this thesis which is not my own work has been identified and that any material that has previously been submitted and approved for the award of a degree by this or any other University has been acknowledged.

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February 11, 2021

UNIVERSITY OF EXETER

Abstract

Department of Archaeology

Doctor of Philosophy

Organisation of Roman Iron production in the Weald

by Ethan GREENWOOD

Iron was essential to the rise and power of the Roman Empire being used for a great variety of purposes from industry and production to military application and everyday domestic use. Significantly, the Weald of Sussex was one of the major sources of iron in Britain. The origins of research into Roman iron production in the Weald were in the early nineteenth century but the key development was the establishment of the Wealden Iron Research Group (WIRG). Since its formation in the 1960s, WIRG has focused research upon all aspect of iron production, creating a free and publicly accessible database of known sites. However, questions still remain regarding the organisation and control of such production sites in the Roman era, with a key area needing further research being the evaluation of industrial waste, especially the quantification of technological waste deposits.

Significantly, this thesis addresses this area to explore the social organisation of Roman period iron production through the investigation, analysis and discussion of two case studies located at Chitcombe and Standen. The research presented in this thesis identifies and interprets archaeological features, most notably deposits of technological waste, to look at the processes of iron production, the role of the sites within the wider landscape, their connectivity and level of influence. In summary, the scale of iron production sites across the Weald is found to vary greatly. Chitcombe is identified as a large-scale industrial iron production site most likely under military control, with evidence for high-level spatial planning with distinct areas for smelting activities and workshops. Standen meanwhile, represents a small scale site with evidence

for a much lower intensity of smelting and no interpretation of control or organisation.

Coupled with a programme of excavation, the application of a multi-faceted geo-prospection methodology, incorporating magnetometry, electrical resistivity tomography (ERT), induced polarisation (IP) and electromagnetic surveys, offering both horizontal and vertical images of the sites, is shown as a positive solution to the notable shortcomings of previous waste deposit studies which lacked an understanding of the waste deposit as a whole because of the impracticality of excavating and analysing such deposits in their entirety. Moreover, the inherent difficulties in assessing the size and nature of technological waste from these sites are addressed and the shortcomings of traditional archaeological survey techniques are highlighted through the identification of reuse of debris across the sites. The strategy designed for the investigations of these sites has created a system of repeatable and comparable datasets that can be built upon with further studies.

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In memory of Peter Walker.
You taught me everything you shouldn't and for that
I am grateful....

1 Introduction

1.1 Theme 1 : History of research into the iron industry in the Weald

The origin of research into the Roman iron industry of the Weald came in 1844 with the observations by Rev Turner of Roman pottery in heaps of cinders that were dug ready for road metalling (Lower, 1849). On further investigations at the source of the cinders, Old Land farm, Maresfield, it was discovered that a building and body had been previously discovered by the workers along with a number of finds of the Roman era that were either disposed of or sold to passers-by. This site and its discoveries were brought to the attention of Mark Anthony Lower, one of the founders of the Sussex Archaeology Society in 1848, who presented the finds at a meeting of the Sussex Archaeology Society and then the British Archaeological Association, before publishing his findings in the British Archaeological Association's volume the following year (Lower, 1849). Within this paper mention is also made to a site in Sedlescombe, which may be reference to Oaklands Park, and also in the parish of Chiddingly. Due to the distribution of these sites across the Weald it could be seen that the production of iron in the Roman era would have utilised the iron ores from across the Weald. Moreover, with Lower being a key member of the Sussex Archaeology Society, their published collections became a vehicle for the publishing of research into the iron industry of the Weald. Therefore, iron-working technologies and their associated technological debris has become an area of academic interest for over a hundred years and covers a wide range of research. This academic interest continues as more understanding is gained into the technological innovation of this industry through space and time and how this in turn affected the contemporary societies.

With the research of the Wealden iron industry, in particular that of the Roman era production, in the eye of academia, a number of individuals began to publish work. Rock (1879), a historian from Hastings, East Sussex, was one of these individuals who reported on the sites at Beauport Park and Chitcombe along with mentioning the un-named sites in Sedlescombe referred to by Lower (1849). Having been local to the area, Rock, previously living in Northiam, concluded that iron production 'had been carried on in every valley between that place and Hastings from the earliest times.' (Rock, 1879 167).

At this time many of these sites were discovered for the purpose of using the material for road metalling and seems to have been focused on the largest of the production sites in the Weald where bloomery slag was present. In academic research many of the sites being discovered were later sites associated with blast furnaces, as the earthworks associated with these types of sites are much more obvious in the landscape.

Throughout the early 20^{th} century one of the most influential contributions was made to the iron industry of the Weald through wide ranging fieldwork which culminated in a monograph written by Ernest Straker (1931). Straker was a bookbinder who was local to the Weald and it was his interest of the local history of the Weald that seemed to drive him in his research (Kaminski, 1995). He worked closely with many other local fieldworkers and researchers focusing the study into the Roman iron production of the Weald and adding many discoveries to the field (Straker, 1931). In this period, different materials were beginning to be used for making roads, therefore iron production sites were no longer being discovered by road workers for people to investigate. Straker (1931) came up with the first methodological approach to the discovery of new sites. The names of fields and places were used to identify areas that may contain iron production, then the knowledge of the local workers was used to pinpoint exact locations. However, Straker (1931) pointed out some issues with this method that still dogs research into the iron industry of the Weald today, including ploughing spreading the slag making it hard to pinpoint the exact location and size of the deposit, or the site being laid to grass or woodland, also making it hard to find. The monograph, *Wealden Iron* (Straker, 1931), was privately published which meant it did not become rapidly incorporated into the circle of academia or wide spread throughout the UK. It may be due to this that there was a decline in research after the death of Straker, with the research available in the academic world being the in-depth study of the larger size sites discovered in the time of Lower (Kaminski, 1995 29-30).

With the onset of World War 2 and the death of Straker, investigation into the Roman iron production of the Weald almost ceased. However, during this time research was being undertaken on the Roman roads of the Weald and how they linked the larger sized sites to the rest of the Weald and the province (Margary, 1965). Also, in this time, the Roman harbour site at Bodium was identified as part of this new understanding of the transport links in the Weald (Lemmon and Hill, 1966 p88-102).

It was not until the 1960's that research into the Roman iron industry of the Weald began to pick up again. This was due to a number of different factors including a change to national agriculture policy after the World Wars, moving from pasture to arable land and larger machines being able to plough heavier clays such as exist in the Weald, the development and growth of experimental archaeology and the creation of local historic and archaeology societies (Kaminski, 1995 32).

One of the local historic and archaeology societies to start in this time was the Wealden Iron Research Group (WIRG), established 1968. The group was established by Henry Cleere and David Crossley and set out to

> *'Advance the education of the public in historical and archaeological study and, in particular, to promote investigation and collate information concerning the Wealden iron industry and related activities for the benefit of the public. In furtherance of this objective a) to publish such information both in regular bulletins and by any other means which the trustees shall think fit: b) to co-operate with and affiliate to other organisations with allied aims as may seem desirable'* (WIRG CONSTITUTION).

Since its establishment, the group has been the leading force in the research into the iron industry of the Weald. Its work includes the discovery of new sites, their identification and dating, along with historical and experimental work in recreating smelting and the other iron production activities. This is recorded into the group's own journal 'Wealden Iron'.

The research that has been completed up to the present in the Weald exhibits some gaps within the literature when it comes to the evaluation of industrial waste deposits from the iron industry, in particular quantification of the technological waste deposit. This is an important section of research as it can inform on scale of production, technology use, and change of processes over time. It has been stated by researchers into the iron industry of the Weald that 'the data available on the area or depth of slag at Wealden sites is very variable, so the volume estimated for sites is, in several instances, arbitrary because of insufficient information' (Hodgkinson, 1999). This point is further backed up in Cleere and Crossley (1995) where they stated that 'no data are available on Oldlands, since most of it has disappeared, but it was apparently comparable in size with Great Cansiron, and so a similar annual production rate may reasonably be inferred. At Broadfields, by contrast, the extent of the slag dump is unknown, but many furnaces have been discovered, and so here again a production of 50 t/a may be assumed'. This shows that there has been a lot of guesswork within the area of research which can have far reaching influences on other areas of study.

The predominant artefact left behind by iron production in the archaeological record is slag and is often deposited in distinct heaps. Another artefact that survives, but not as frequently as slag in the archaeological record, is the furnace which is used to produce the iron. A large amount of the literature that is available on this subject is based on the research looking at these two specific types of artefacts due to them being very interconnected with one directly influenced by the other. For example typology of the furnace has been a large area of research as this can show how the furnace itself functioned allowing an understanding of technology being used at the time (Cleere, 1972; Coghlan, 1977; Martens, 1978; Pleiner, 1978; Serning, 1978; Tylecote, 1986). The typology of slag is also well researched as this also can allow for the smelting techniques to be recognised (Bray, 2006). Some studies focus on the technical aspects of smelting as a whole looking at the furnace, chemical reaction and by-products (Craddock, 1995; Pleiner, 2000; Rostocker and Bronson, 1990; Tylecote, 1986, 1987, 1992) both these areas of research again allow for the assumptions to be made about the technology of production along with the efficiency of the workforce. A number of studies have taken the technical aspect of smelting and placing its production into its wider landscape based on a geographical location, and looking at its wider influences on society. Examples include the study of Sri Lankan iron production (Juleff, 1998), iron production in the southwest of Britain (Bray, 2006), iron production in the Weald (Cleere and Crossley, 1995; Hodgkinson, 2008), and iron production along the Jurrasic Ridge (Schrufer-Kolb, 2004).

The waste deposits left behind on iron production sites are often heterogeneous in their composition with the constituent parts being variable in their representation across waste deposits within a site, and also between different waste deposits. This has made investigating waste deposits difficult and estimating their constituent parts and volume even more so. Research was conducted by Cleere and Crossley (1995) to estimate the volume of waste deposits and the slag within, and the results of these studies have seemingly become the accepted source for estimations within the Weald, without any repeat data. Rundberget (2017), Humphris and Carey (2016), Bray (2006) , and Juleff (1998) have also done studies on volume analysis of waste deposits in Norway, Sudan, Exmoor, and Sri Lanka respectively. Due to the difficulty of estimating the volume of the waste deposits and the fact there are very few repeat studies to back up the estimations being used, it is possible that studies based on these estimations could be inaccurate. A good example of this would be the grading of sites into size category (Hodgkinson, 1999). This information is then used to look at the wider production landscape, particularly in the Weald, to try and understand such things as the socio-economic conditions, land use, deforestation and transportation. Therefore, these estimates have a snowball effect, reaching far into other areas of research. Despite this challenge a number of projects have made a considerable contribution to our understanding of these waste deposits through excavations (Bray, 2006; Cleere, 1970; Humphris and Carey, 2016; Juleff, 1998; Rundberget, 2017). These sources look mainly at the composition of waste deposits and changes within waste deposits due to variations in technology and practice. However, it is difficult to understand waste deposits as a whole due to this variation and the impracticality of excavating and analysing entire waste deposits.

One answer to this issue is the use of geo-prospection surveys on metallurgical sites. Types of surveys that measure the magnetic responses have been used in identifying the position of sites and features such as waste deposits and furnaces (Vernon, McDonnell, and Schmidt, 1998). The use on metallurgical sites of a wide variety of geo-prospection surveys, in particular to estimate depth and volume of the waste deposits and any features that are buried within the waste deposits, has seen development in recent years. There are a number of studies that stand at the forefront of this development including research by Florsch et al. (2011), Ullrich, Wolf, and Kaufmann (2014), Meyer, Ullrich, and Barlieb (2007), and Humphris and Carey (2016). These studies use a variety of geo-prospection techniques including Earth Resistivity Tomography, Induced Polarisation, and Ground Penetrating Radar, in order to calculate the depth of the waste deposits, which in turn could be used to produce a more accurate volume, and to identify any large features buried within. Rundberget (2017) has also added to this research using topographic surveys and excavation, rather than geo-prospection, to calculate waste deposit volumes in south-east Norway, with a discussion and critique of the accuracy of methods used.

Many of the iron production sites throughout the Weald have been identified through people actively going out and seeking them. This may have led to a bias of the number of sites discovered in certain areas and not in others, giving a misrepresentation of how they are dispersed and spread across the landscape. This could lead to a mis-interpretation of areas of control or major areas of production. Moreover, one of the most accepted and used methods to discover iron production sites is to look along river and stream, banks and beds for the waste products where they are more easily seen and identified, as they have been washed out of the technological waste deposit. This may again then create bias into the assumption that iron production sites only exist on the slopes next to a stream of river leading to a possible mis-representation of the dispersal of sites across the landscape. This could also lead to sites being missed due to rivers or streams silting up over time and placing the sites now away from modern day water sources, or missing sites that were originally positioned away from water sources.

Of the 1133 metallurgical sites that have been discovered in the Weald 594 are undated. Much of the dating that occurs is completed through the analysis of pottery, placing the site in often a broad time period due to the long existence of many types of pottery. It is also often not a common discovery on the site and involves the time and resources of excavation to identify and document.

Another under-represented area of research is the wider site identification. Often sites are identified due to the discovery of waste products and the position recorded in the landscape. However, this does not allow for a true understanding of the sites position in the landscape as there is no information on the spacial layout on the site, size of production, full date range of use, or control and use.

1.2 Theme 2 : The intersection of Archaeology, archaeometallurgy, and geo-prospection

The discipline of archaeology can often be seen as one of the black sheep of the academic world. It sits in a sometimes uncomfortable, and often muddy, grey area between the STEM subjects and the humanities. However, for archaeologist this is a rare gift that very few other subjects can enjoy. This allows for the field of archaeology to become symbiotic with other disciplines which means a much deeper understanding of the subject can be reached. Further to this within the discipline of archaeology there are a number of sub-disciplines that exist on a sliding scale with some sitting nearer to the end of STEM subjects and others positioned towards the humanities. Archaeometallurgy, which is the study of how humans produced and used metal, is one of these sub-disciplines that has a tendency to sit much closer to the STEM subjects, being heavily science based with research looking at the physical and chemical constraints of the processes surrounding iron production (Craddock, 1995; Pleiner, 2000; Rostocker and Bronson, 1990; Tylecote, 1986, 1987, 1992). Geo-prospection is a field that sits between physics and geography/geology, and looks at the physical properties of the earth using different techniques. This is a good example of how archaeology has reached into another discipline for its own advancement.

Killick (2005), identifies that 'metallurgy is a human behaviour - metals do not mine or smelt themselves'. This means that the production and use of any metal is inherently connected with the rest of human life, from culture to society and economics. This gives both archaeology and archaeometallurgy common ground in which research can thrive.

The use of geo-prospection surveys in archaeology are frequent and widespread with a variety of different techniques being used to detect different anomalies. This is because, compared to excavation, some surveys are relatively quick which means a large area of land can be investigated. Moreover, the surveys are mostly non-intrusive, which means that there is no destruction of the archaeological record. This is another example of how archaeology has utilised techniques from other disciplines with all of the geo-prospection survey types originating in geology and earth sciences (Reynolds, 2011). In the right hands these surveys can allow archaeologists to identify specific features within a site and give a larger picture of the archaeology across an area than could be seen with only excavation. It also allows for the protection of archaeology as some features can be understood through the surveys alone, which means excavations are not necessarily needed and it also allows for features to be accurately located, allowing small test trenches to be used rather than wide scale excavations. Although all these techniques can be used individually they are often used in conjunction with each other. This is due to the fact that different surveys techniques detect different physical properties, and combining more than one type of survey would complement each other and give a more in-depth understanding.

The scientific framework of how different survey types work will be covered in Chapter 3. The physicality of the use of these techniques fits within the remit of archaeological fieldwork and, with modern computer power, the results produced consist of a map of variation in the specific physical property being measured. Geo-prospection surveys are frequently used in archaeology to produced a two dimensional birds-eye view image of features across a site in order to better target excavations. However, it is believed that geo-prospection surveys have a much greater ability to inform on specific features.

By drawing the disciplines of archaeology, archaeometallurgy, and geo-prospection together a much deeper understanding can be reached. Care must be taken that the core approaches and vigorous methodologies of each discipline should be adhered to in order to collaborate and answer broader research questions.

1.3 Aims and Objectives

The socio-economic influence of production underpinned society in Roman Britain, as it does today. To understand the socio-economic influence of a site, wider site features need to be identified and interpreted, such as working practices and habitation. Moreover the scale, volume, and constituent parts of the technological waste deposit need to be identified as well as the potential number of furnaces being utilised, allowing for an understanding of scale and organisation of production. This would then in turn inform on the place of the site in the landscape, not just in space and time, but also in its connectivity and influence.

This thesis aims to address this in a multi-factorial way. One way will be to investigate a more accurate way of calculating the true volume of iron production waste deposits from the Roman era to understand more precisely the scale of production. This will be done through the use of a combination of geo-prospection techniques allowing investigation of the spatial extent and positioning of the waste deposit and wider site features. This use of geo-prospection techniques to inform on features in the horizontal and vertical planes, show that geo-prospection can be used as more than just a tool for the locating of features in the field of archaeology, but also showing the form of the feature informing on shape and potential preservation, as well as giving measurements for calculating volume. A database of physical properties, such as magnetism, resistivity, and conductivity can also be compiled allowing for an understanding of materials present and a comparison of features and anomalies.

Another way this thesis aims to investigate the organisation of iron production is to quantify and characterise the technological waste from within the technological waste deposit to gain a true understanding of what forms the waste deposits and the development and changes that occurred in technological practice. This will be done by collecting a large data-set of material through excavation from two sites which can then be analysed to give a greater understanding of the formation and constituent parts of the waste deposits.

With this new information on site organisation and waste material quantification, a more accurate understanding can be reached on the potential social climate of the Roman iron industry in the Weald of South East Britain.

The aims of this project are to:

- Gain an understanding of the social organisation of Roman iron production in the Weald.
- Test methods for investigating iron production sites to calculate the horizontal and vertical extent of deposits, with a focus on the technological waste deposit
- Quantify and characterise technological waste to gain a true understanding of what forms waste deposits and the developments and changes that occurred in technological practices.

These aims will be addressed through the following objectives:

- Use a combination of geo-prospection techniques to investigate the spatial extent and depth of the waste deposits in order to measure and calculate a more accurate volume.
- Excavate a number of test pits of known volume into the waste deposit to ground truth the geo-prospection data and generate several data sets of technological waste with which to help quantify the makeup of the waste deposits.
- Sample and analyse the technological waste to give information on constituent volume, technological processes and dynamics of deposition.

1.4 Thesis layout and terminology

This section will set out the narrative of the thesis showing how the reader will be guided through this project. It will also set out a number of terms used throughout this thesis and their specific meanings.

1.4.1 Thesis Layout

The layout of this thesis will guide the reader though, building the understanding of the associated background history and methodological approach to understand why this research is being undertaken and how the conclusions have been drawn.

Chapter 2 will contextualise the Weald and the process of iron production. It will begin by defining the Weald in its geological and environmental setting as well as outlining the iron industry in the Weald in its entirety to help show the longevity of this industry and how it developed and declined across time. The process of iron production will then be set out covering the collection and processing of raw materials including ore, refractories, and charcoal, and how these are subsequently used to smelt ore to metallic iron. The physical and chemical constraints of all these processes will be set out. All products created in iron production, including waste, will be discussed and the literature will be assessed to understand what remains are left in the archaeological record. A discussion will then be had on the use of geo-prospection for the investigation of iron production sites

Chapter 3 will set out the methodological approach of investigation. It will explain how the sites used in the two case studies were identified and chosen for investigation. Details will be given of the geo-prospection surveys used, including how they work and what they detect, along with how they are used in the field. The methods used for excavations will be set out along with what analysis will be completed on finds collected.

Chapters 4, 5, 6, and 7 will look at the two case studies investigated for this project, chapters 4 and 5 relating to Chitcombe and 5 and 7 Standen. Each case study has been divided into two sections the first primarily looking at the geo-prospection surveys and data (chapters 4 and 6), and the second looking at the excavation, material collection and classification (chapters 5 and 7).

Chapter 8 will look at the analysis of the geo-prospection from both sites, focusing on a number of key features identified in the case studies.

Chapter 9 will look at the methodological choices and approaches used for the investigation of metallurgical sites in this project which will critique how this project was undertaken, and if the approaches used are viable for continued use in the investigation of metallurgical sites in the future leading to a greater accuracy in interpretation and understanding.

Chapter 10 will discuss the wider landscape interpretation of Roman iron production across the Weald in light of new evidence discovered through this project. Wider interpretations of each case study will be set out and then these interpretations compared. A discussion will then be had on other iron production sites investigated throughout the Weald, how the case studies from this project fit with these and if current knowledge or interpretations have been changed, concluding this thesis.

1.4.2 Terminology

A number of terms used throughout this thesis may seem to have obvious meaning, but some need an explanation as to their choice of use.

Technological waste deposit, or variation thereof, is the term that is used when describing the primary deposit of by-products left over from the smelting process. In many pieces of literature this is referred to as the 'slag heap'. However, this term is misleading as the deposit is formed of more than just slag, and across the Weald is not represented as a clearly defined 'heap', but as a changing spread of deposit along ghyll-sides.

Roman as an adjective comes with a certain amount of inference that it was a mono-culture with everyone in the empire adhering to the same set of values and social beliefs. With the Roman empire stretching from Egypt to Scotland this would be a huge over simplification. Therefore, within this thesis 'Roman' will be used to identify politics, military, time period, or when it is clear there is a differentiation with circumstances that include local British influence. Whereas the phrase Romano-British will be used when discussing the Weald and iron production within its bounds when there is no clear separation in control by the Roman establishment, and the population of Britain within the Roman era.

Industry could be perceived as a loaded term with modern day western inferences of mass production of a product in a factory setting. To maintain continuity with definitions in research the term industry/industrial will be used when discussing the later blast furnace production. However, this term will only be used in a strict framework when looking at Roman and Romano-British sites. This will be discussed in more detail in Chapter 8.

Iron production is going to be used to refer to the processes used to produce metallic iron by the direct or indirect method. This will not include smithing as this is moving from raw material production into product production which would have its own socio-economic influences.

2 Contextualisation of the Weald and the process of iron production

2.1 Introduction

This chapter will look to set out some of the key literature and information needed in order to contextualise and understand the research conducted throughout this thesis. It will begin by defining the Weald due to its position, geology and environment. The history of iron production throughout the Weald from Iron Age through to modern times will be set out to give the reader an understanding of the longevity and socio-economic importance of the Weald as an iron producing area.

A more generalised understanding of the process of iron production will then be set out covering some of the key literature in this area and allowing the reader to understand what this process produced both as a product and by-product and how this may affect and be left in the archaeological record.

This chapter will conclude with a synthesis of the key literature pertaining to the application of geo-prospection surveys on metallurgical sites.

2.2 Defining the Weald

This section will place the Weald in its geological and environmental setting helping to inform on reasons for the placement of long standing iron production throughout the landscape.

2.2.1 Geology

The Weald is an area of land in the southeast of Britain covering parts of the counties of Sussex, Kent, Surrey and Hampshire. It is well defined by its geology (Fig2.1), consisting of a central area of sands and clays being bound by the chalk escarpments of the North and South Downs. The North Downs are truncated by the English Channel at Dover and extend north and west through Wrotham and Wye to Guildford and to Farnham in Hampshire. The South Downs extend from Alton, south-east wards through Lewes, and are again truncated by the English Channel at the Seven Sisters. The North and South Downs are connected by the Butser hills (Kaminski, 1995 52).

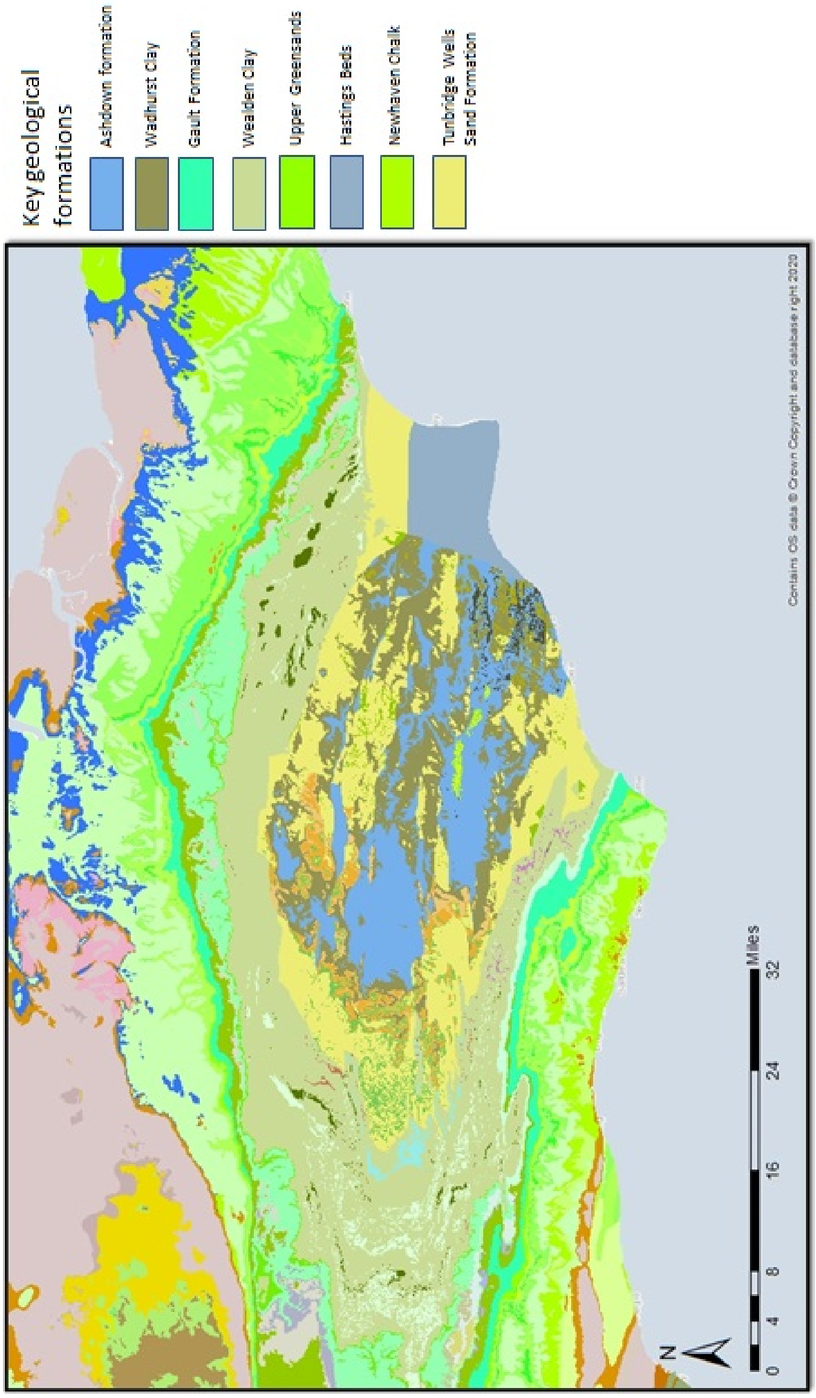


FIGURE 2.1: Geological map of the Weald

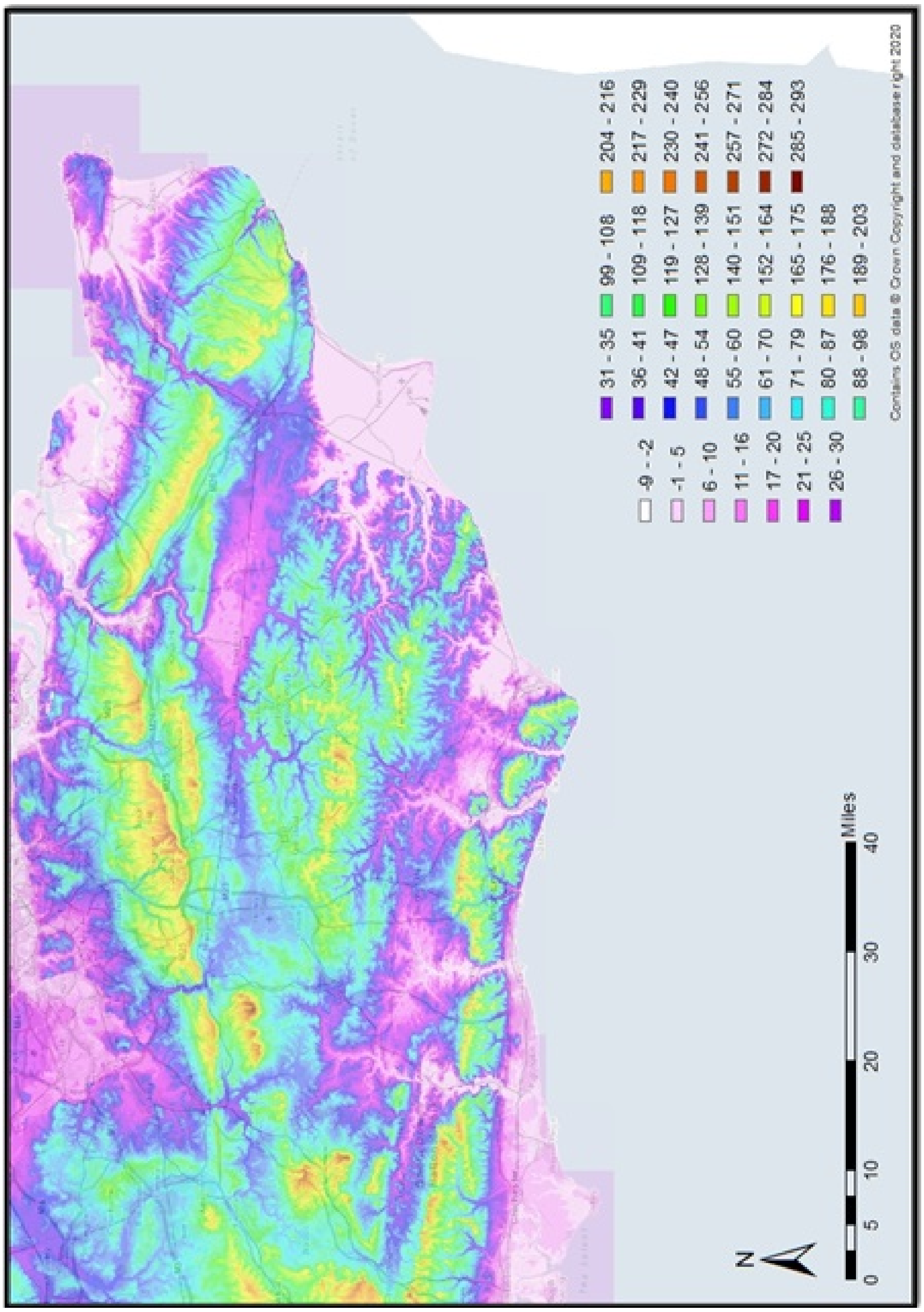


FIGURE 2.2: Topographical map of the Weald

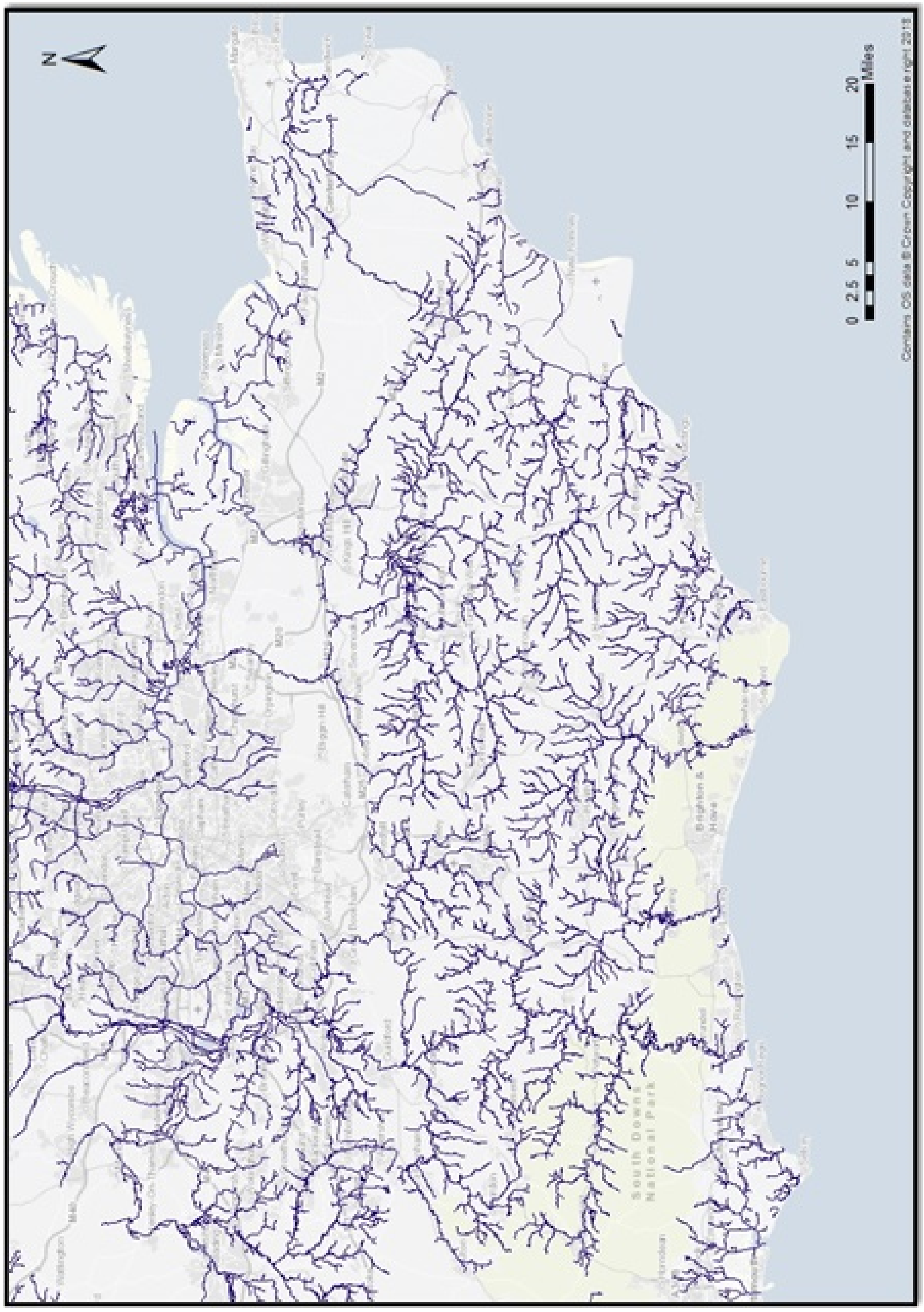


FIGURE 2.3: Map of waterways in the Weald

The geological deposits of the Weald have been split into distinct groups. The earliest of these, which formed at the very end of the Jurassic and the first 20 million years of the Cretaceous, are the Wealden Beds. This umbrella group is formed of two sub-groups. The Hastings Beds, which form the lower part of the Wealden beds, are made of the Purbeck Beds, Ashdown Beds, Wadhurst clays, Tunbridge Wells Sands and Grinstead Clay. These layers consist of mainly sands with bands of clay and inclusions of ironstone beds in almost every layer. The upper part of the Wealden Beds are formed of Weald Clay. This layer does not have sub-layers and is mainly formed of clays with occasional inclusions of sands, Horsham stone and ironstone. On top of the Wealden beds are deposits of Greensandsand then chalk which form the upper level of the Wealden geology (Worssam, 1995 2). When the Wealden beds were deposited the area was a large freshwater to brackish lake. This lake spread from just south of London, through the southeast of modern Britain and across the channel to the present day Normandy coast and southeast through the Pays de Bray. This lake was fed by rivers crossing current day Britain and France depositing sediments, clays and sand (Worssam, 1995 3-5). Microbial action at this time then concentrated iron into the bands we see today as ironstone (Hodgkinson, 2008 10).

At the end of the Cretaceous period land subsidence gave way to rise due to the geological event of the African continent crashing into the European continent. This rise caused the Weald to dome, leading to faulting and smaller folding of sections of the Wealden beds and anticline across the whole of the

Weald. Once the geological layers started to rise back above sea level denudation started to occur. This was brought about by general weathering but also most notably by the rivers which cover the Weald (Fig2.3). Many of these start in the centre of the Weald and cut ghylls and valleys through the Weald, taking the shortest path north or east to the outer Weald. With the uplift forming a dome, in modern times the central Weald is formed of the older geological layers as there has been a longer period of denudation whereas the outer Weald is formed of the Greensands and Chalk due to less time for denudation to occur (Hodgkinson, 2008 9-10).

The Weald can be split into 3 physiographic zones: the High Weald, the Low Weald and the periphery (Fig2.2). The High Weald extends from Hastings northwest to Horsham forming the centre of the Weald and the anticline. It reaches heights of around 240m above sea level and is formed of the oldest of the Wealden strata, as has been discussed.

The High Weald is defined by its complex faulted geology leading to the telltale ridges and ghylls. These strata also give rise to highly acidic, poorly drained and infertile soils which give way to a wide range of ecologies from woodland to heathland (Kaminski, 1995 61-63). It is within the High Weald that many of the iron production sites sit. There are many factors why this may be, which will be discussed later in this thesis. The Low Weald is a ‘U’ shaped corridor encircling the High Weald with its two truncated ends at Pevensey and Romney. It is formed of denuded Wealden clay, in which, due to its plastic state, little faulting has taken place, therefore creating an undulating landscape with heights of up to around 130m above sea level. These strata are more fertile than the High Weald and have historically supported extensive pasture and woodland, along with marshland on the coast (Kaminski, 1995 65-66). The periphery is a zone that surrounds the Low Weald, and sits between that and the chalk escarpments, and is formed of three concentric bands of Upper Greensand, Gault Clay and Lower Greensand. It reaches heights of up to around 300m and supports fertile, well drained soil (Kaminski, 1995 67-68).

2.2.2 Environmental

There is evidence for manipulation of the flora of the Weald from the Mesolithic on-wards. This most likely started with small-scale manipulation of the local vegetation and clearance leading to the favouring of pioneering species such as hazel, birch and heather (Kaminski, 1995 99-100). Into the Neolithic pollen of taxa that are common anthropogenic indicators start to become more significant such as edible grasses. This carries on into the Bronze Age, with the scarce archaeological remains showing that predominant habitation was on the peripheral zones. However, this may be down to archaeological bias. Into the Iron Age the Weald sees the start of wide-scale changes to the fauna and wide ranging human habitation in hill forts and the start of iron production, which by the late Iron Age was utilising large amounts of wood for fuel, including charcoal. This trend carried on into the Roman period with a large increase in iron production, leading to a larger manipulation of the local vegetation (Kaminski, 1995 102).

The different layers of geology in the Weald have tell-tale flora signs on the surface. The most obvious is the chalk escarpments which are covered predominantly with grass. Within the central Weald on the older geological layers, such as the Ashdown Beds, the flora tends to consist of large areas of heath-land which forms a major part of the Ashdown forest. The Wealden Clays which are one of the most common geological layers exposed in the central Weald tend to be covered in pasture or woodland. This may be where the Weald gets its name from which is derived from woodland in old English (Worssam, 1995 8-9).

2.3 The history of iron production in the Weald

For all the data collected throughout this project to be understood in a wider 'landscape' setting, the historic background of the Weald and all its influences need to be understood. This includes the long and rich history of the Wealden iron industry and a more specific history of Roman Britain to put the iron industry at the time into context.

The Wealden iron industry ran almost continuously for 2000 years from the mid to late Iron Age through till the early 19^{th} century. With an industry running for this length of time it is no surprise that it has left its mark on the landscape with physical alterations such as mine pits, waste deposits and ponds, and placenames such as the many 'Cinderfields' that exist throughout the Weald.

The southeast, including the Weald, has seen some of the most influential events in the history of Britain from the invasion by the Romans in 55-54BC and 43AD and the Battle of Hastings in 1066. This rich social, political and industrial history is highly interconnected. Neither of these are standalone nor are the influences linear, but they are all interconnected. This means that an understanding is needed of these different histories to understand trends and changes that may occur and therefore how this may influence what is being seen in the archaeological record.

This section will cover the history of iron production in the Weald from the pre-Roman Iron Age, through the Roman period and into the post-Roman and Medieval, informing the reader on the narrative of production through time.

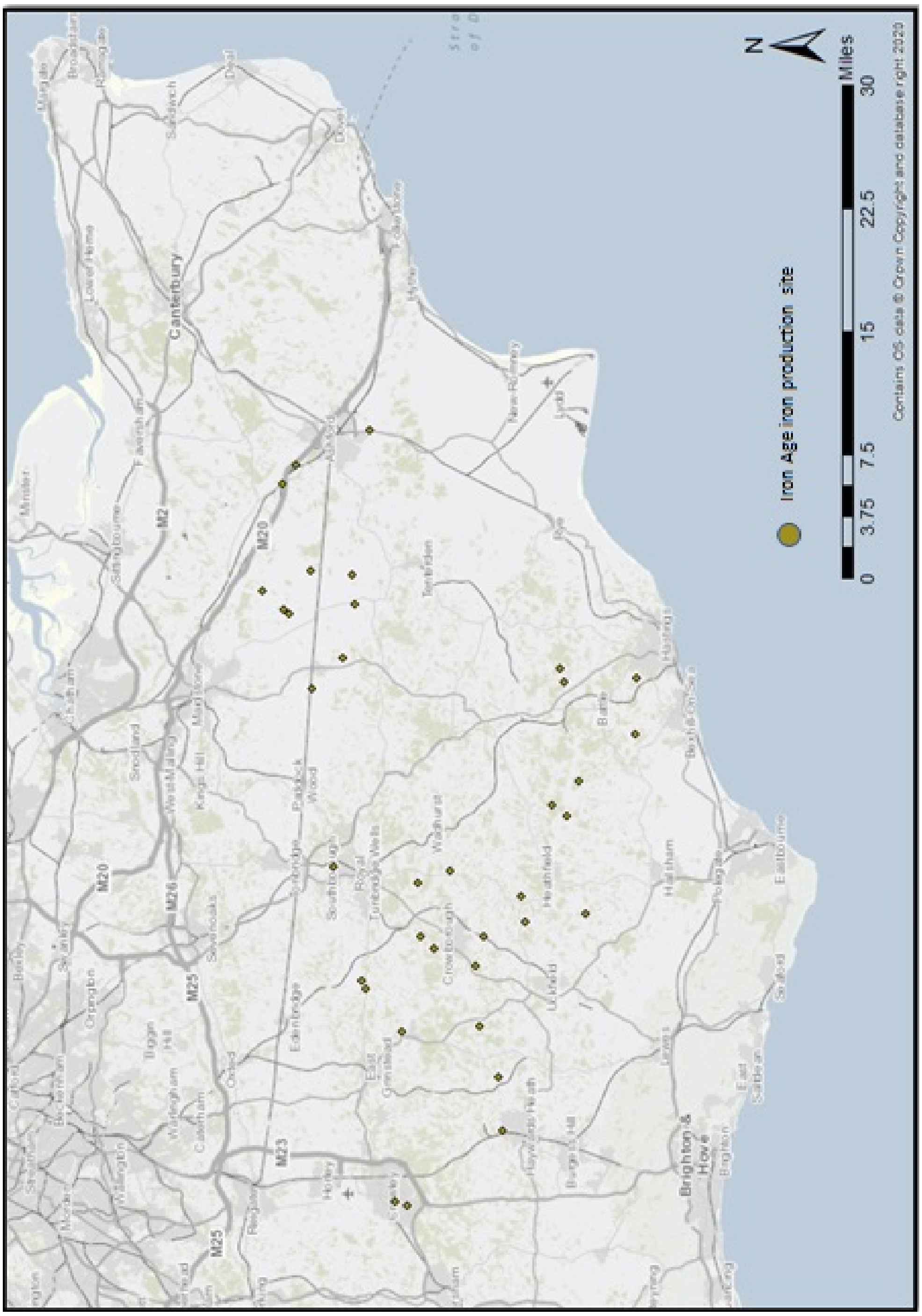


FIGURE 2.4: Distribution of Iron Age iron production sites

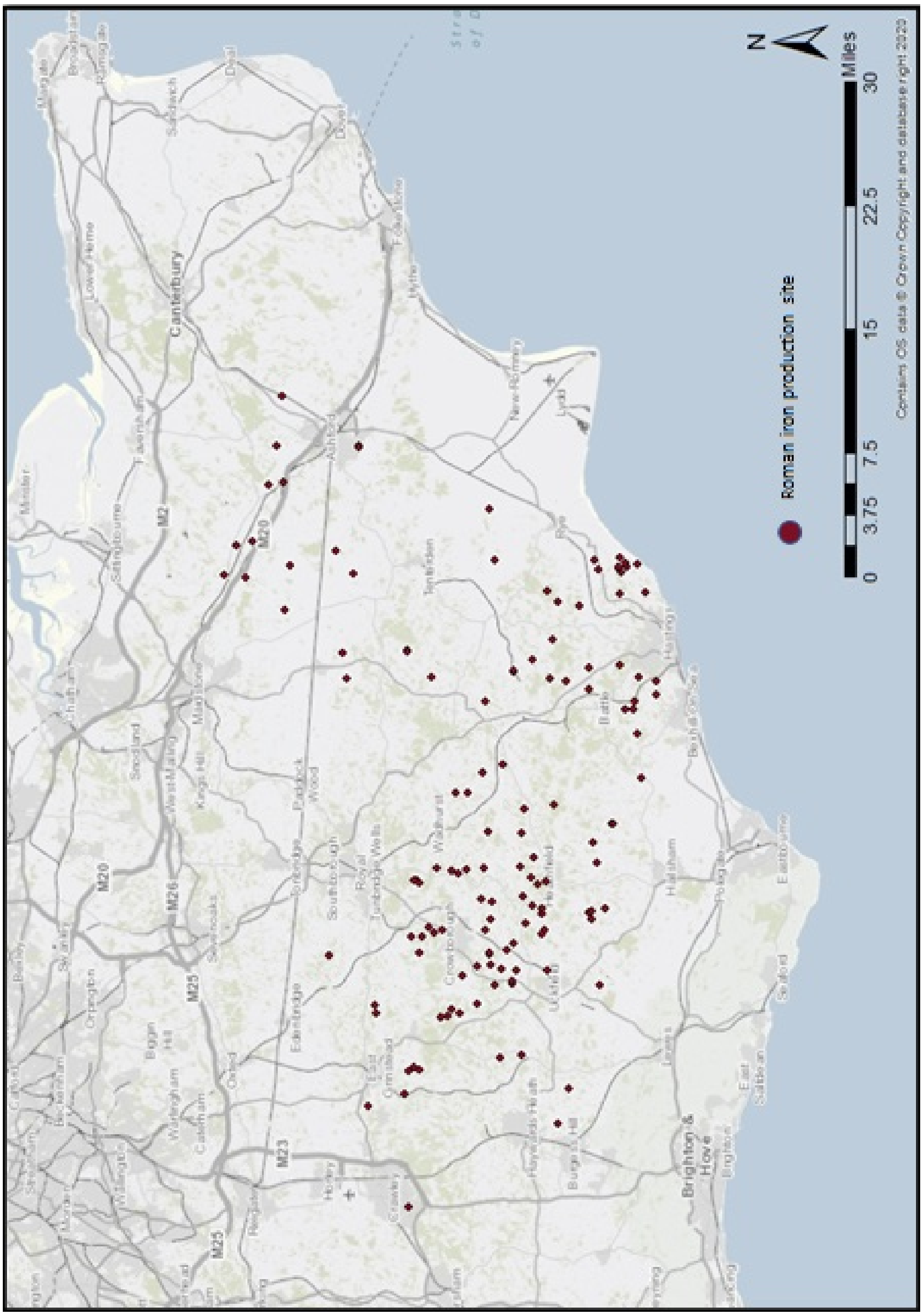


FIGURE 2.5: Distribution of Roman iron production sites

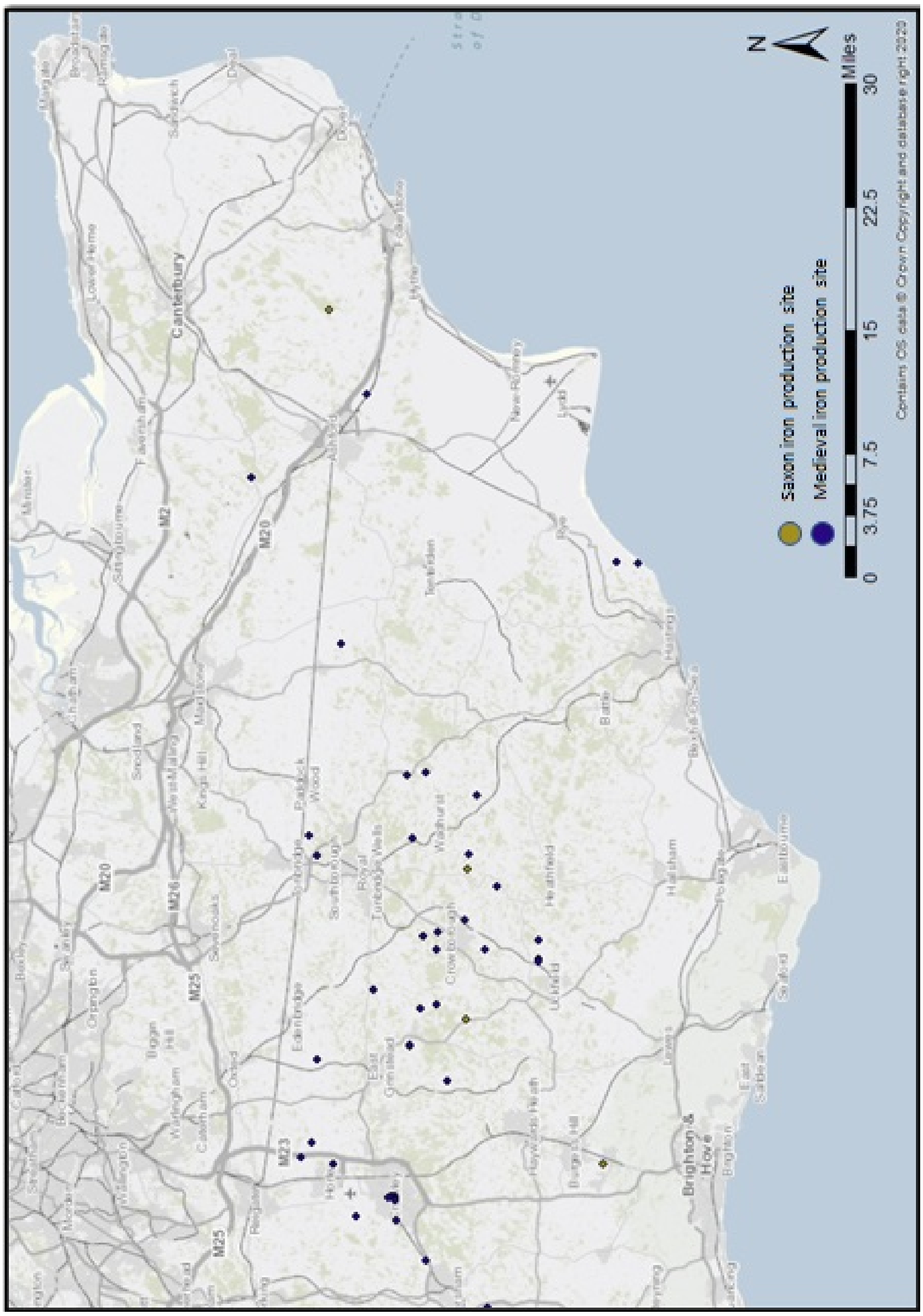


FIGURE 2.6: Distribution of Medieval iron production sites

Iron Age

Iron is generally believed to have been first used in Asia minor from about 2000BC (Tylecote, 1992 47). In Britain iron is not seen until around the 7^{th} century BC, and at this time it is not being smelted but rather traded from mainland Europe (Tylecote, 1986 124). It is not until the La Tène period that the use of iron increases and evidence begins to emerge of smelting taking place in Britain (Tylecote, 1986 124).

There is reference to iron production in pre-roman Britain in ancient texts. Caesar himself writes around the time of his invasion in 55-54 BC, mentioning iron being produced in small quantities in the maritime region of Britain (Caesar Gallic Wars V, 12). As there are no other known iron production areas on the coast of Britain at this time, Caesar is most likely to be referring to the Weald. When Strabo writes about Britain around half a century later he lists iron as one of the major items traded out of Britain along with hunting dogs, slaves, grain, hide, cattle, gold and silver (Strabo Geography IV, 5). This suggests that iron production was potentially increasing quickly up to the Claudian invasion of AD43.

This history correlates with the archaeological evidence currently available from the Weald. At the time of writing there are 38 sites in the Weald that have been attributed to the Iron Age (Fig2.4). One such site is Tablehurst Farm, Forest Row that has been radiocarbon dated to between 370BC to AD30 with a

95.4% probability, narrowing to between 210BC to AD30 at a 68.2% probability, placing it within the expected date of the Iron Age of the Weald (Hodgkinson, 2004 4). The site at Cullinghurst Wood, Hartfield, has also been radiocarbon dated to between 750-350BC, at a 90.5% probability (Hodgkinson, 2006 2), which would make it much earlier than anything previously recorded in the Weald. Both these radio-carbon dates are single measurements with no repeats or supporting evidence, so although this data can be relied upon more, more data could be obtained for a more accurate interpretation.

Broadfield, Crawley is a site that sits on the western extent of the Weald. The site has been extensively excavated (Gibson-Hill, 1976 23-32) and has been shown to be a site that was in use from the 2nd century BC into the Roman era. Of the roughly 60 furnaces discovered on the site there seems to be no evidence of technological advancement or evolution of form once the Romans arrived even though a variety of forms were discovered (Hodgkinson, 2008 28).

A number of iron production sites have been found in conjunction with fortified Iron Age settlements including Garden Hill in Hartsfield, Piper's Copse in Northchapel, and Saxonbury in Frant (Hodgkinson, 2008 29). When it comes to organisation of the iron industry in Iron Age Britain, there have been no firm conclusions or interpretations. With possible influence from three 'tribes'; the Cantiaci, the Atrebates, and the Regni, it is very difficult to say which had influence and control over specific areas within the Weald, and for what duration, with almost no information being known about their land boundaries, and minimal knowledge on their socio-economic organisation (Hodgkinson, 2008 29-30).

Roman

Iron was essential to the rise and power of the Roman Empire. It was important, as today, in all aspects of life. Iron was used extensively in all walks of life from industry and production, military applications, and simple domestic use. Examples include tradesmen's tools, from building to agriculture and everything in between, along with daily domestic equipment, structural fittings, and military equipment including armour and weapons (Sim, 2012). In Britain, the Weald was one of the major sources of iron and by the end of the first century iron was one of the most traded items around Britain (Russel, 2006).

The earliest investigations of the Roman iron industry in the Weald were made by Lower (1849) in the mid- to late nineteenth century and Straker (1931) in the 1930's. It must be assumed that some of the sites were known about beforehand as they are commonplace throughout the Weald and would have interfered with modern agriculture, due to the waste deposits being difficult to plough. Also field names including the word 'cinders' are common throughout the Weald. The investigations began, in many cases, due to items, such as pottery and coins, being discovered when the slag from the waste deposits were being quarried to make roads (Cleere and Crossley, 1995). In more recent times, the majority of exploration and research into the iron industry of the Weald has been undertaken by the Wealden Iron Research Group.

The Weald was an ideal location for iron production in the Roman period due to its excellent geological conditions for all aspects of the iron production process, its position for transport to the rest of Britain and across the smallest stretch of the English Channel to Europe, and the fact that there was already iron being produced across the Weald in the Iron Age (Stevens, 2013). It can be seen in the archaeological record that the invasion and occupation of Britain by the Romans in AD 43 had a major effect on iron production across the Weald, causing a large increase in output (Cleere and Crossley, 1995). This may be due to the Weald being near to the believed invasion point, which means the area may have become important in the early production of military equipment for the invasion and occupation of Britain.

To date there are believed to be nearly 700 bloomery iron production sites in the Weald. However, out of these only 191 have been dated with 127 of these being of Roman date (Fig2.5). Since this thesis was written all of these numbers would have likely increased with new sites being discovered fairly regularly and even more being dated. A system to categorise these sites has been defined by Hodgkinson (1999) in which the sites are split into grades depending on the volume of their waste deposits (tab:2.1).

It is estimated that the total volume from waste deposits in the Weald is around 148000m^3. Difficulties can arise in the estimation of volume due to the fact that over time slag has been systematically quarried from sites for road metalling or hard-core. There is evidence of this removal almost continuously from the Roman era to the modern day. In some cases, such as with roads this loss of slag from the waste deposits could be quantified with in-depth investigation of the structure and formation of the deposit. However, if there is evidence on the iron production site of quarrying of the technological waste deposit but there is no evidence of where the material was utilised, then at best an estimation can be made of the amount removed and at worst this loss of information will make any interpretations based on volume inaccurate.

TABLE 2.1: Grade of iron production site based on waste deposit volume

Grade	Size(m^3)	% representation
1	<100	48%
2	100-1000	32%
3	1000-10000	16%
4	>10000	4%

According to Cleere and Crossley (1995) the amount of iron believed to have been produced in the Weald during the Roman era increased rapidly from the invasion of AD 43 to its peak between AD 150 and AD 250. There were then two periods of decrease in the output of iron in the Weald, the first just after AD 250 with a short reprieve and then the second around AD 350. The reason for the increase and decrease would be multifactorial. For example, the sharp increase could be down to the military need for iron, plus the eventual Romanisation of the locals would have created a large demand for iron for everyday objects and needs. The first decrease could have been down to the reorganisation of the Classis Britannica under the Emperor Severus which saw the closure of large bases such as Dover and Beauport Park. The Classis Britannica was a fleet set up by the Roman State to assist with the development of the new province of Britannia. This included transportation of military personal and raw materials across the English Channel and around the province. Their main base in Britannia was at the port of Dover, with two smaller bases at

Pevensey and Chichester. Tiles stamped with the symbol of the Classis Britannica (CL:BR) have been discovered at seven Wealden sites; Bardown, Beauport Park, Little Farningham, Bodiam, Kitchenham Farm (Cornwell and Cornwell, 2014a), Northiam (Cornwell and Cornwell, 2017), and Castle Croft (Cornwell and Cornwell, 2018b). Moreover, during this time there was an increase in coastal raids from pirates which means the Classis Britannica may have had to devote more of their time to combating this problem rather than other duties such as iron production (Mason, 2003). The second of the decreases coincides with the abandonment of Britannia by the Roman Empire which means there may not have been the level of consumption of iron in the general population or military. Other factors that could have influenced either decline is that the waterways of the Eastern Weald began to silt up which would have made transportation by these waterways increasingly more difficult. Also, with the high level of production, raw materials may have begun to run low, such as wood for charcoal due to deforestation, which means other areas such as the Forest of Dean may have become more profitable and accessible (Russel, 2006).

A theory is still discussed when looking at the organisation of the Roman iron production across the Weald that the area was split into two distinct groups, the Eastern and the Central (Russel, 2006). This split may be due to the fact that in the Roman era all mineral deposits were owned by the State, with the area where they were located being known as an Imperial Estate. The law of State ownership of mineral deposits was not stated until the reign of Vespasian (AD 69-79). It has, however, been widely accepted that a form of this law existed prior to this (Cleere and Crossley, 1995). It is believed that the State took control of deposits of precious metals, as these had a higher financial pay-back and were important for the control of wealth, whereas the rights to less precious metals was rented out to individuals and private companies. It could be argued, however, that with the invasion the need for iron made it a valuable commodity to keep out of the hands of the local population, who could themselves use it produce weapons.

There is an ongoing debate within research in and around the Weald as to whether or not the Weald was an Imperial estate. Within the area of the Weald there is very little major settlement, with villas only existing on the Chalk Downs that encircle the Weald (Hodgkinson, 2008). Moreover, there seems to be evidence showing direct involvement from the state in the form of the Classis Britannica, particularly in the Eastern group (Cleere and Crossley, 1995). When looking at the transport links it can be seen that the sites of the proposed Central Group are positioned along major roads and have very little state involvement. Moreover, when looking at the proposed Eastern Group the sites are positioned along or near major waterways and have the best evidence of state involvement through stamped tiles of the Classis Britannica (Cleere, 1971). Much of this evidence forms the basis for arguments as to whether the whole, part, or none of the Weald is an Imperial Estate.

Post-Roman Medieval

The archaeological record shows a cessation in the iron industry from the early fifth century, when the Romans left Britain, until around the middle Saxon period. The site that shows the earliest evidence of post-Roman iron production is Millbrook, Ashdown Forest. This site has been radiocarbon dated to between AD 666-907 with an archaeo-magnetic date of AD 800-920, these dates are also supported by middle Saxon pottery discovered during rescue excavations of the site (Tebbutt, 1982 19-35).

The form of the furnace discovered at Millbrook was of a more 'primitive' design compared to what had been seen previously in the Weald during the Roman period. However, this type of furnace is similar in form to one excavated in eastern Netherlands, which could show that the continuity of smelting in the Weald was broken and then reintroduced by the Saxons from their continental homeland (Hodgkinson, 2008 35). Another piece of evidence that may help show this discontinuity between the Roman era in the Weald and the Saxon period is the lack of Celtic or Roman based placenames (Hodgkinson, 2008 35). The only other site that may belong to this time period in the Weald is Long Gill, Mayfield, which has been radiocarbon dated to AD 315-785 (Cattell, 1972). However, as with other sites this is a single carbon date with no repeat or other substantiating evidence, therefore caution should be taken.

In the Doomsday Book, which was compiled in the late 11^{th} century, there is only one reference to ironworking in the Weald. This was described as *una ferraria*, on an un-named manor near to East Grinstead. It is likely that what is referenced is a smithy that would have been attached to the manor house for making iron implements for the house and land (Hodgkinson, 2008 36). Although not widely recorded in the written history there have been to date 45 sites identified from this time period dispersed across the Weald (Fig2.6)

By the mid-13^{th} century, documentary evidence is available for iron production in the Weald. This comes in the form of orders and purchases of iron and iron items such as horseshoes and nails. These purchases were made by the Crown from the estates of the Archbishop of Canterbury for, in one instance, 8000 horseshoes and 20000 nails. The largest order of around this time was for 30,000 horseshoes and 60,000 nails (Cleere and Crossley, 1995 88). This volume of iron being ordered in one go, along with the smaller orders for everyday implements, shows that iron production was back up to a high level with the ability to produce large quantities in a relatively short time. At this time iron was still being produced as blooms in bloomery furnaces.

Blast Furnace industry

The main difference between bloomery furnaces and blast furnaces is that in a bloomery furnace iron is produced in a solid form, whereas in the blast furnace the iron is produced in a liquid form, which is discussed in more detail later in this chapter. The blast furnace was larger in every respect compared to the bloomery furnace. It was physically a much larger construction using a larger amount of raw materials and producing a larger amount of iron. This meant considerably more investment was needed both in start-up costs and labour, which could be the reason that most of the early blast furnaces were in the hands of the Church or Crown (Hodgkinson, 2008 49). It also left a much larger mark on the landscape with some relatively large earthworks being created for such aspects as ponds to hold water to power the bellows. Smelting in the blast furnace was often started after the harvest, around October time, and would continue throughout the winter and into late spring. This would be so that there was enough rain to replenish the pond which powered the furnace

(Hodgkinson, 2008 53). Due to the iron and slag both being produced in liquid form, smelting could continue non-stop for the duration and the products tapped off when the base of the furnace started to get too full. If the furnace was to 'blow out', stop running and cool down, then it would take around a month to repair and reheat for smelting which would be a substantial amount of time lost.

The end of the 15^{th} century saw a significant change in the Wealden iron industry with the introduction of the blast furnace. This technology was already being used on the continent from the 12^{th} century but earliest records show it to have moved to the Weald in 1490, at the site of Queenstock, Buxted (Hodgkinson, 2008 63). This change established blast furnace technology from the continent in Britain, leading to the phasing out of bloomery furnace technology, and allowing the growing iron markets of the Crown and London to be met. It would also go on to allow the development of new and innovative methods for casting iron (Cleere and Crossley, 1995 111). With this new technology came the need for a new set of skilled practitioners. In the Weald these positions were filled by French immigrants who would have been used to the technology back on the continent.

The blast furnace industry ebbed and flowed in the Weald until the late 18^{th} century when production had moved to the Midlands and the north, with the final furnace closing in the Weald in 1813 and the final forge closing in 1827 (Hodgkinson, 2008). The blast furnace industry saw many fluctuations through its existence due to the political landscape across Europe leading to many wars, as well as an expanse in invasion, colonisation, and trade on a global scale.

2.4 Research into iron production

The history of iron production is a major area of research and covers a broad array of themes, including technical processes, geographical regions, chronological periods, and the socio-economic context of production, with many drawing on archaeological evidence or experimental reconstruction. Many studies do not just focus on iron but on the process of metallurgy as a whole, focusing on its technology in the work of such people as Tylecote (1986, 1987, 1992) and Craddock (1995). While others such as Pleiner (2000) and Rostocker and Bronson (1990) look more directly at the processes of iron production and how they have evolved over time. Some works have looked at how these processes have created an industry and how this fits into a wider landscape, focusing on specific geographical areas, and drawing on many research themes. These include works by Cleere and Crossley (1995) looking specifically at the Weald of south-east England, Schrufer-Kolb (2004) on the Jurassic ridge of the east midlands and Bray (2006) on the Exmoor region of the southwest of England.

There is a growing number of experiments undertaken to recreate aspects of iron production. These are to try and understand in real terms what the remains that are found in the archaeological record mean, and try to understand aspects of the process that don't leave any physical remains. In experimental recreations by Juleff (1998) in Sri Lanka, the entirety of the smelting process was recreated, including charcoal production, ore processing and roasting, furnace construction and a full smelt. Similar studies have been undertaken by the Wealden Iron Research Group which has been experimentally recreating the smelting process as part of an ongoing project including ore mining, preparation and roasting as well as full smelts (Herbert, 2015). There have also been experiments in the Weald to see how ore roasting pits were covered to understand remains in the archaeological record (Prus and Herbert, 2007). Experimental reconstruction has also been used to answer more specific questions such as the fuel used and what fuel is best (Gjerloff and Sorensen, 1977; Norbach, 1997), as well as how the type of furnace affects the smelt (Boonstra, Manakker, and Dijk, 1997; Juleff, 1998).

To explain the dynamics of iron production and the industry that surrounds it an understanding is required of the processes that are needed to obtain the final product, which is the iron, and how variations in these separate processes could have further influences on the wider dynamics of the industry and beyond. The succeeding sections will outline the four stages needed to complete a smelt. These are mining, ore processing, charcoal production and smelting, along with how the end product is further processed by smithing, and how all these are represented in the archaeological record.

2.5 Mining

This section will look at the various aspects of material collection that exists under the umbrella term of mining. The potential types of iron ore will be looked at as well as the possible techniques used in retrieving the ore.

2.5.1 Ore deposits and minerals

Iron is the second most abundant metallic element in the Earth's crust. However, as it is chemically reactive it exists as a wide range of minerals. From the point of view of the production of iron, the most important of these are the oxides, such as magnetite (Fe_3O_4) and haematite (Fe_2O_3); the carbonates, such as siderite ($FeCO_3$); and the hydroxides, such as limonite ($Fe_2O_3.3H_2O$) and goethite ($FeO.OH$) (Rostocker and Bronson, 1990 42). These oxides, carbonates, and hydroxides are defined as ore minerals as it is from these that the metal is extracted. These ore minerals occur, mixed with unwanted minerals and native rock, often called gangue, within the local geology (Bray, 2006 35). These ores are then extracted from the ground if they are deemed to have a high enough ore mineral content for economic exploitation.

Whether an ore is deemed to be viable for economic exploitation is a subjective judgement depending on a variety of factors. These could include, technological, economic and social factors. First and foremost the iron content in the mineral must be of a high enough concentration to obtain metallic iron at the end of the smelt. Secondly, the ore needs to contain an appropriate ratio of ore minerals to gangue to allow the formation of liquid slag. A liquid slag is necessary to allow the unwanted material to flow away from the metallic iron separating the product from the waste.

There is a wide variety of iron ore deposits spread throughout the world, based on morphology, chemistry and the environment and time period in which they were formed (Young, 1993 446). Due to there being such a variety throughout the world, this section will focus on the main ores from Britain with a summary of the mineral in Table 2.2 (Rostocker and Bronson, 1990 42).

TABLE 2.2: Major iron minerals

Name	Chemical Formula	Iron Content
Magnetite	Fe_3O_4	72.35
Hematite	Fe_2O_3	70.00
Specularite	Fe_2O_3	70.00
Goethite	$FeO(OH)$	62.85
Limonite	$FeO(OH).nH_2O$	<62.85
Siderite	$FeCO_3$	48.21
Pyrite	FeS_2	46.60
Greenalite	$(Fe, Mg)_6Si_4 \cdot O_{10}(OH)$	33.80-37.50
Chamosite	$(Fe, Mg)_{3,6}\,(O, OH)$	28.50-37.3

In Britain the ores that contain these iron minerals often have unique names due to what they form in and where they form. Three major ores that have been used in Britain for iron production are:

Blackband – siderite ore that occurs in rich organic sheets, often associated with coal deposits, and can reach extents of tens of kilometres (Young, 1993 457). These were used by pre-industrial and early 19^{th} century smelters (Rostocker and Bronson, 1990 42).

Bog ore – limonite ore which forms in pods of lenses in bogs and are often discovered under peat. These were important to many early smelters due to them forming near to the surface so are easily accessible (Rostocker and Bronson, 1990 p42).

Clay ironstone – siderite ore which forms into concretions within clay and can exist as large sheets or disseminated nodules (Young, 1993 p458). This ore can be relatively impure and care must be taken as it is sometimes incorrectly just named 'ironstone' which is a vague term used to describe ores that cannot be identified. This type is of particular importance as it is clay ironstone that is predominant in the Weald, and the ore type that was used in Roman iron production (Rostocker and Bronson, 1990 43).

In the context of the archaeology of mining, ore deposits can be divided into three basic types. Sheet-like, characterised as being tabular in shape including lenses, veins and sedimentary beds of ores. Stocks, characterised as irregular bodies of ore with well-defined boundaries. Impregnations, characterised as the infilling of spaces within the native rock with ore minerals with poorly defined boundaries (Baumann, 1976 p4-5). This classification is based on the morphology of the ore deposit as a whole which is then the main factor in the way it is exploited by mine workings.

These types of ores are seen all across Europe and all played an important role in the early iron industry. For example bog ores, which fall within the impregnation category (Bray, 2006), are found across the European plain from northern France to northern Russia and have been used since the Iron Age (Pleiner, 2000 88). In Britain in the Roman era, sheet-like and stock deposits were the most exploited forms of ore. The siderite nodules of the Weald being confined to the Wadhurst clay (Worssam, 1995 10-13) and the oolitic ironstone of the Jurassic Ridge (Schrufer-Kolb, 2004 13) are both examples of sheet-like deposits. The ore found within the carboniferous limestone of the Forest of Dean (Green, 1992 p165) and the mineralised lodes and veins of the Exmoor region (Bray, 2006) are both examples of stock ore deposits.

2.5.2 Prospecting and Mining

In order for the ores to be extracted through the process of mining, they first need to be discovered and recognised which is the act of prospecting. Modern day prospectors have sophisticated techniques at their disposal, including geo-prospection and geochemistry, with which to discover ores. In the past,prospectors relied upon a number of field observations to identify ores. One way of discovering and recognising ore deposits is by the way the ores look. When ore deposits outcrop they are exposed to weathering by the elements which usually leads to the ore minerals changing into oxides or hydroxides. Iron minerals that are exposed to weathering will become a colour on the scale of browns, reds, oranges and yellows (Bray, 2006 36-37). Outcrops of ore deposits are usually situated on hills or valley sides which have been cut by a river, which means they would be easier to identify in a wider landscape context.

Once the area was known for the presence of iron ore then test pits may have been dug in order to find other ore sources in the local vicinity. Another way in which ore deposits could have been discovered is the change in flora and fauna in its vicinity. Brown (1995) describes how smiths in Kenya look for certain types of grass and certain species of rat and beetle to show that there is iron ore within the soil. Also Worssam (1995), shows that in the Weald the geology that the ores are in has a distinctive type of foliage cover with Wadhurst clay being covered with trees and pasture and the Ashdown beds being covered in heathland.

Once discovered and recognised the ores then need to be mined. The methods by which ores are mined can be put into two distinct groups, surface and underground. These two forms of mining could have taken place individually but also co-existed on mining sites (Woods, 1987).

Looking at surface mining, the simplest technique would have been to simply collect the weathered ore from the surface (Bray, 2006 37). A possible example of collecting ore like this comes from the Burgenland area of eastern Austria where nodular sedimentary clay ironstone was collected from the surface (Pleiner, 2000 90). When the scale of production needed to be increased, for instance to cater for increased demand, then pits could be dug to reach the ore deposits or follow them from where they outcrop. There are many examples of these pits, or opencast mining, throughout Europe including the Donaumoos plain, near the Danube in southern Germany where there are a number of pits ranging in diameter up to 10m and around 0.5m deep, believed to be dug to gain access to the bog iron ore of the area (Pleiner, 2000 94). Also, Kelheim in Bavaria, where there are a number of pits ranging from about 5m to 15m in diameter and 0.7m deep, dug to gain access to limonite nodules. Again at Thoste in France, and Zamora in Spain, large open pits have been discovered ranging from 80m to 1km in length (Pleiner, 2000 94). Ore pits are a common feature throughout the landscape of the Weald covering all time periods of iron production. Many of these are difficult to date due to a lack of datable evidence, lack of investigation, and in many cases similar form of the opencast mine. One example from the Weald that has been securely dated to the Roman period is the site at Petley Wood where open cast pits measuring 15m to 20m in diameter and 15m deep have been discovered (Worssam, 1995 16). Others such as those seen throughout Forewood, Crowhurst (Fig2.7), and elsewhere can be best seen throughout the wetter months when they flood and form small ponds.

FIGURE 2.7: Flooded minepit, Forewood, Crowhurst

Due to the relative abundance of iron ore outcrops, most iron ore was extracted using the opencast technique. However, where veins of ore dived deeper into the geology or the ore was for more valuable metals, such as copper, underground mines were used. Underground mining techniques in the Roman period used horizontal passages known as adits and galleries, and vertical shafts, to follow the vein of ore or to try and intersect with a known ore vein (Woods, 1987 613). There are many examples of underground mines throughout mainland Europe, one of which is a mine at Knicht, near Lolling, Germany, which was dated to the second half of the third century AD and contained the scattered skeletal remains of two miners and their tools, which could be evidence of an ancient collapse and show the dangers that were faced by miners (Pleiner, 2000 97-98). Although the use of underground mines was quite common on mainland Europe, in Britain there is little evidence of their use for the purpose of extracting iron ore. A rare example is from Lydney Park in Gloucestershire where a shaft and gallery were found sealed under a Roman site with the opening to the mine being around 1mx6m (Wheeler and Wheeler, 1932 18).

The type of ore extraction that was used was dependent on a number of factors which could include technical expertise, availability of ore, demand for production and the local geology. Out of these factors, geology would probably be the most influential. The Roman mines in Spain are a good example of this. In the south the geology predominantly consists of hard rock, with the archaeological record showing widespread underground mining, and in the north soft rock, with the main mining practice being opencast surface mining (Woods, 1987 612). This could be due to the fact that the soft rock geology was not as stable, therefore would have been dangerous for underground mining. Moreover, once a vein of ore was discovered in hard rock it would have been easier to follow with mine shafts rather than digging lots of pits through the hard rock to access it. It is likely then that this is the reason there are, to date, no underground mines of Roman date in the Weald as the ore is discontinuous due to geological fault lines and the geology the ore is deposited in is soft (Worssam, 1995 6).

By the early Roman period iron handheld tools seem to have become commonplace within the mining industry, but there were still some ores and host rocks that were too tough to be mined with these tools (Bray, 2006 40). To help resolve this issue the technique of firesetting was used.

Firesetting is a technique by which heat is directed towards a rock face in order to crack and soften it, making mining of the ore easier (Timberlake, 1990b 49). This was done by piling up wood against the rock face, in such a way that the heat is directed towards it, and set alight, being continuously topped up until the desired affect had been reached or wood ran out (Timberlake, 1990a 53). Experimental reconstruction of this process has shown it to work effectively (Crew, 1990; Lewis, 1990; Timberlake, 1990a).

With iron being such a valuable commodity in everyday living since the Roman times, many deposits have been exploited repeatedly since then. This repeated exploitation has potentially led to the destruction of much of the archaeological evidence, in particular when looking at modern day mining methods. For this reason there has been a belief amongst many archaeologists that it is therefore not worth searching for the remains of earlier miners, but this has been proven to be a rather despondent view (Bray, 2006 41). An example of why this is comes from Great Orme, Wales, where bone tools and hammerstones were discovered in the mine workings and a carbon date from charcoal placed it in the Bronze Age (Timberlake, 2003 23).

In the Weald an open cast mining site at Petley Wood has been solidly dated to the Roman period due to the large amount of pottery found in the overburden of the opencast pits, some measuring up to 20m in diameter (Worssam, 1995 16), showing such sites have not been re-used in later time periods. The reason these sites were not reused could be down to the fact that the Romans used up all the viable ore, or that when the smelting technology changed from direct to indirect the idea of what a viable ore was may have changed due to the different economic understanding of yield. However, there has not been a wide scale investigation and dating of iron ore mines across the Weald, therefore no firm conclusion can be made.

2.6 Ore processing

Once the ore has been mined it then needs to be processed in order to prepare it for smelting. This processing changes the ore both chemically and physically and can be split into two main stages, ore sorting and ore roasting.

2.6.1 Ore sorting

Ore sorting does not seem to be a single stage process but rather an ongoing process from when the ore is extracted to when it enters the furnace for smelting. The ore sorting process may have started off with washing which would have cleaned off any soil or clay that the ore was in (Sim and Ridge, 2002 44). However, the main purpose of ore sorting would have been to concentrate the high density minerals by removing any unwanted rocks and any low grade ores that would not have been effective for smelting (Schrufer-Kolb, 2004 7).

Once the ore was roasted, any large pieces remaining would have been mechanically broken into appropriate sized pieces for smelting. These pieces had to be big enough to allow the hot reducing gasses in the furnace to flow around them for a long enough period of time by not dropping through the furnace to quickly but small enough to allow a larger reaction surface area to maximise contact with these reducing gases. Discoveries in the Weald of large deposits of roasted ore fines of below 5mm within the waste deposits may show that the size of ore used for smelting was above this size (Cleere and Crossley, 1995 35). However, this is only one example and size might have differed depending on the smelting technology being used.

Further ore sorting may have occurred once roasting had taken place. Evidence of this may be seen at Ridlington, Rutland, where a refuse tip of roasted ore and limestone was discovered (Schrufer-Kolb, 2004). This process would then again be used to help concentrate the ore minerals. It could also show how valuable a commodity the ore was, with pieces being roasted that were of lower quality in case they were enriched enough to be viable for smelting. It could also be an insight into the ability of the smelters to identify which ores are going to create a successful smelt or not.

2.6.2 Ore roasting

In many cases iron smelters would have found it advantageous to roast the ore before smelting. Ore roasting, also known as calcining or elyng, has the effect of oxidising carbonate ores into oxides (Hodgkinson, 2008 15). It also has the effect of physically changing the ores. One way it does this is to soften the ore, which means it can be more easily broken into smaller pieces hence increasing the reactive surface area (Sim, 2012 p34). Another way it alters the ore physically is by removing water, therefore drying it out. This part of the process can be quite dangerous with the pressure building up to such a point that the ore can explode breaking it into smaller pieces (Sim, 2012 34) but also fracturing it on a micro scale further increasing the reactive surface area and allowing the hot gases in the smelting process to penetrate into the ore (Bray, 2006 45).

Carbonate ores such as siderite ($FeCO_3$) have to be roasted to a minimum temperature of 560^oC in order to oxidise the iron carbonates to the iron oxide wustite (FeO) with subsequent oxidation reactions occurring in an oxygen-rich environment producing other iron oxides such as haematite (Fe_2O_3) and magnetite (Fe_3O_4) (Alkaç and Atalay, 2008).

$FeCO_3 \rightarrow FeO + CO_2$ (initial decomposition)

$4Fe_O + O_2 \rightarrow 2\gamma Fe_2O_3$ (possible oxidation reaction)

$6FeO + O_2 \rightarrow 2Fe_3O_4$ (possible oxidation reaction)

$4FeO + O_2 \rightarrow 2\alpha Fe_2O_3$ (possible oxidation reaction)

There are a variety of forms of iron ore, many of which technically do not require roasting. For example limonites ($2Fe_2O_3.H_2O$) and goethites ($FeO.OH$) could be smelted straight from the ground, but by roasting them it is possible to release free and combined water and cause micro-cracking (Pleiner, 2000 p108).

Limonite: $2Fe_2O_3.H_2O + heat \rightarrow 2Fe_2O_3 + 3H_2O$

Goethite: $FeO.OH + heat \rightarrow Fe_2O_3 + H_2O$

2.7 Charcoal production

Fuel supplies the heat that drives the smelting and refining processes. Charcoal was the main fuel used in the iron smelting process in antiquity due to it being a near pure source of carbon and having no water content, it burns at high and consistent temperatures making it easier to control. Also, it is an excellent source of carbon monoxide which allows the reduction of the ore to take place during smelting. Moreover, it contains very few impurities with which to contaminate the iron, unlike coal which has high levels of sulphur. Charcoal is also relatively easy to produce due to the ease of acquiring wood from which it is made (Sim, 2012 25), although in some cases, such as the island of Elba, high quality iron ore was moved to the mainland due to lack of wood for roasting and smelting (Sim and Ridge, 2002 41).

2.7.1 Wood selection and management

There is reference in ancient texts that shows there was an awareness of the different properties of wood and how this affected the charcoal produced. In his Natural Histories (Book XVI, 403) Pliny the Elder notes, in reference to broad leaf oak:

> *'As charcoal it only pays to use it in a copper-smith's workshop, because as soon as the bellows stop it dies down and has to be rekindled repeatedly; but it gives out a great quantity of sparks. A better charcoal is obtained from young trees'.*

Theophrastus in his Enquiry into Plants (Book V, 468-469) states:

> *'The best charcoal is made from the closest wood, such as aria [holm-oak] oak arbutus; for these are the most solid, so that they*

> *last longest and are the strongest... Worst of the woods mentioned is oak, since it contains most mineral matter, and the wood of older trees is inferior to that of the younger, and for the same reason that of really old trees is specially bad. For it is very dry, wherefore t sputters as it burns; whereas wood for charcoal should contain sap. The best charcoal comes from trees in their prime and especially from threes which have been topped: for these contain in the right proportion the qualities of closeness admixture of mineral matter and moisture... But different kinds of charcoal are used for different purposes: for some uses men require it to be soft; thus in iron-mines they use that which is made of sweet chestnut when the iron has already been smelted...'*

However, the archaeological record does not seem to show this bias towards different species of wood for fuel quality but rather towards the predominant species in the area of use. This can be seen in the representation of alder as a source for charcoal production which is high in Scotland, northern England and Wales but a low in the archaeological record of southern England (Sim, 2012 29). This correlates with its distribution throughout the woodlands of Britain. At the Wealden site of Bardown, the studied charcoal remains showed eight species of tree being used to produce charcoal, with oak being the most commonly represented, as would be expected from the ratio of tree species present in the woods of the Weald (Cleere and Crossley, 1995 37). As can be seen, this is in contradiction to Pliny and Theophrastus who state that oak does not produce a good quality charcoal. But in an area that is dominated by oak it would seem logical to use that tree and put effort into making more charcoal if necessary than going out over a larger area to collect a specific type of wood. The broad range of species of tree found on a site may lend itself towards the idea that different wood was used for different processes. However, unless the species of charcoal are recorded stratigraphically and associated with a specific process it is hard to tell if this was the case or if they were just using the nearest available wood.

There seems to be inference in the texts by Pliny and Theophrastus, that younger wood, or trees in their prime, produce better charcoal. This point does seem to be backed up with evidence from the archaeological record of the Weald showing the use of young wood to produce charcoal (Sim, 2012 29). Rackham (1980) suggest that after initial tree clearance and regrowth, the Roman iron industry would have maintained the woodland with some form of coppicing practice. However, it is rare for a large volume of charcoal from an archaeological site to have been studied in enough detail to tell if it was natural regrowth or coppiced wood (Sim, 2012 30).

2.7.2 Charcoal production

Charcoal is produced via the thermal decomposition of wood. As a material, wood is formed of many different compounds which include cellulose, hemicellulose, pectins, terpenes, mineral salts, alkaloids and ancillary oils (Pleiner, 2000 115).

The process of turning wood to charcoal consists of slowly burning the wood in an atmosphere that is starved of oxygen, up to temperatures of roughly

450^{o}C to 500^{o}C (Pleiner, 2000 115). This causes the wood to release its water content, which in green wood can be 60% and dry wood 20%, along with other volatile substances. This produces charcoal which is up to 92% carbon (Pleiner, 2000 115). The species of tree and the specific part of the tree being used to make charcoal can have an effect on the amount of carbon and other compounds, which can in turn affect its ability to produce carbon monoxide, which can then in turn affect the smelting process itself (Pleiner, 2000 115). There is very little evidence in the archaeological record for how the process of turning wood into charcoal was carried out in the Roman period. However, looking at evidence of charcoal production from later dates it could be assumed, based on the little archaeological evidence and process parameters, that it was done in a similar way. The wood was stacked tightly together with smaller chips of wood filling most of the gaps in successive layers until a cone shape was formed, this was then covered in a layer of fern and clay, with holes to allow the fire to be lit and a small amount of oxygen to enter, and set on fire. Once the fire had burned though all the holes were covered with clay and the wood left to burn for a number of hours (Pleiner, 2000 119).

2.8 Smelting

This section will look at the furnaces, and materials used for their construction, before setting out the two processes, indirect and direct, by which iron can be smelted and the scientific framework within which iron smelting sits. Indirect smelting will be briefly covered first as it becomes significant in the blast furnace technology in later periods in the Weald. Direct smelting will then be set out in greater detail as this is the framework used for smelting in the Roman period.

2.8.1 Furnaces and refractories

Structures associated with smelting, such as furnaces, hearths and tuyeres, must be created from materials that are poor thermal conductors, which means they should keep the heat within the furnace rather than radiating it out, and maintain a solid state. They must also be structurally sound, and have low reactivity, as to not interfere with chemical processes occurring.

An abundant source of these oxides is within clays, which are in themselves a versatile building material. Clays are poor thermal conductors, which is another property of the oxides they contain. This property does bring with it some issues in the way of thermal shock. When clay is heated it expands and when cooled it contacts. If a furnace is heated or cooled too fast then it can cause the clay structure to crack causing structural instability and loss of temperature. This means that practically the structure would have to be heated and cooled slowly. Due to clay being malleable, other inclusions can be added and mixed through the clay to increase such properties as structural integrity by reducing its disposition to thermal shock, prolonging the life of the structure which means, for example in a furnace, multiple smelts can be completed as is evident at Cow Park and Broadfield in the Weald (Cleere and Crossley, 1995 38). More evidence from the Weald, specifically the site of Holbeanwood, shows that pieces of burnt clay, presumably from old broken furnaces, were incorporated as inclusions as these would have expanded or contacted to a lesser extent reducing the chances of cracking (Cleere and Crossley, 1995 38).

Evidence from Kenya shows considerable amount of knowledge surrounding the properties of clay. A mixture is produced of equal parts local clay and clay from termite mounds. It is mixed to the correct consistency on a hardened dung floor, because if loose soil entered the mixture it would cause it to crack upon heating (Brown, 1995 57). Evidence and reconstruction from Sri Lanka also shows that complex clay mixtures were used in building furnaces. This includes a mixture of paddy field mud, termite-mound earth, river sand, red alluvial gravel, fresh and chard paddy husk and straw. This mixture was created by the local community when asked for a clay mixture that would be able to handle high temperatures of the furnace (Juleff, 1998 177).

Stone can be used within larger structures for structural integrity. However, many rocks act as poor refractories as they either have low melting points or become crumbly upon heating (Rostocker and Bronson, 1990 59). One family of rocks that do perform well in furnaces are sandstones. These do not fracture on heating or cooling, and due to being formed of predominantly silica have poor heat conductivity (Rostocker and Bronson, 1990 59). Sandstone is also easily quarried and cut, and in the case of the Weald is closely associated with both clay and iron ore.

2.8.2 Direct and indirect smelting

To produce metallic iron the ore needs to be reduced through the process known as smelting. Throughout space and time this has been done through a number of different methods which follow two main 'routes', the direct or indirect process.

The indirect smelting process converts the iron ore into forgeable iron in a two stage process. The first of these two stages creates cast iron, which has a high carbon content of between 2 to 5 %, in a blast furnace (Rostocker and Bronson, 1990 107). This cast iron is extremely brittle and cannot be forged. However, it can be used to cast certain items such as firebacks. This cast iron then goes through a refining process in order to obtain a steel, which has a carbon content between 0.2 to 1.5 % carbon, which is hard enough for use but soft enough to be forged. This refining process is known as decarburisation or puddling (Rostocker and Bronson, 1990 139).

In a blast furnace the conditions are such that the amount of carbon monoxide is significantly greater than carbon dioxide (Rostocker and Bronson, 1990 p102). Due to such high reducing conditions the temperature needed to create liquid slag is high which means over 1350^{o}C needs to be obtained. Moreover, due to these high reducing conditions, more carbon is absorbed into the iron. The cast iron produced has a lower melting point than pure iron which means at 1350^{o}C a liquid iron is produced. The liquid iron and liquid slag then form into pools in the bottom of the furnace which, due to their difference in densities, form one on top of the other, the more dense iron being on the bottom. These can then be tapped off individually with the slag being discarded and the iron being cast into bars, known as pigs, hence the name pig iron, ready for the refining process (Rostocker and Bronson, 1990 33).

The direct smelting process converts the iron ore into forgeable iron in a single process, hence the name. The iron produced can either be pure iron, wrought iron, low carbon steel, or an admixture of all three. This happens in what is customarily known as a bloomery furnace, due to the iron produced being in the form of a bloom, which is a spongy mass of iron and slag. Blooms are formed in this solid state reduction due to the melting point of pure iron being around 1530^{o}C. This temperature are difficult to reach and maintain to produce liquid iron, therefore a liquid slag is formed to flow away from the solid bloom. The iron produced is relatively soft allowing it to be forged with no further processes. However, the fact that the iron is soft, due to its low carbon content, means that it may be inappropriate for certain uses, such as blade edges. Therefore, it could undergo the process of carburisation in which the iron is heated for a long period of time in a high carbon environment, for example buried in a charcoal bed, giving way to surface absorption of the carbon producing small amounts of high carbon steel (Rostocker and Bronson, 1990 121). This carbon steel would be harder, which means it would be better for holding an edge, while still being soft enough to forge. As this was the technique used throughout the Roman Empire, and the evidence it leaves behind is the focus of this study, this technique will now be looked at in greater depth.

2.8.3 Smelting process in a Bloomery furnace

In antiquity, across most of western Europe, iron smelting took place in bloomery furnaces. The shape, size, and form of the furnace itself can vary greatly. This is because at a basic level it is a purpose-designed refractory, durable container which allows for specific chemical reactions and environments to occur in a

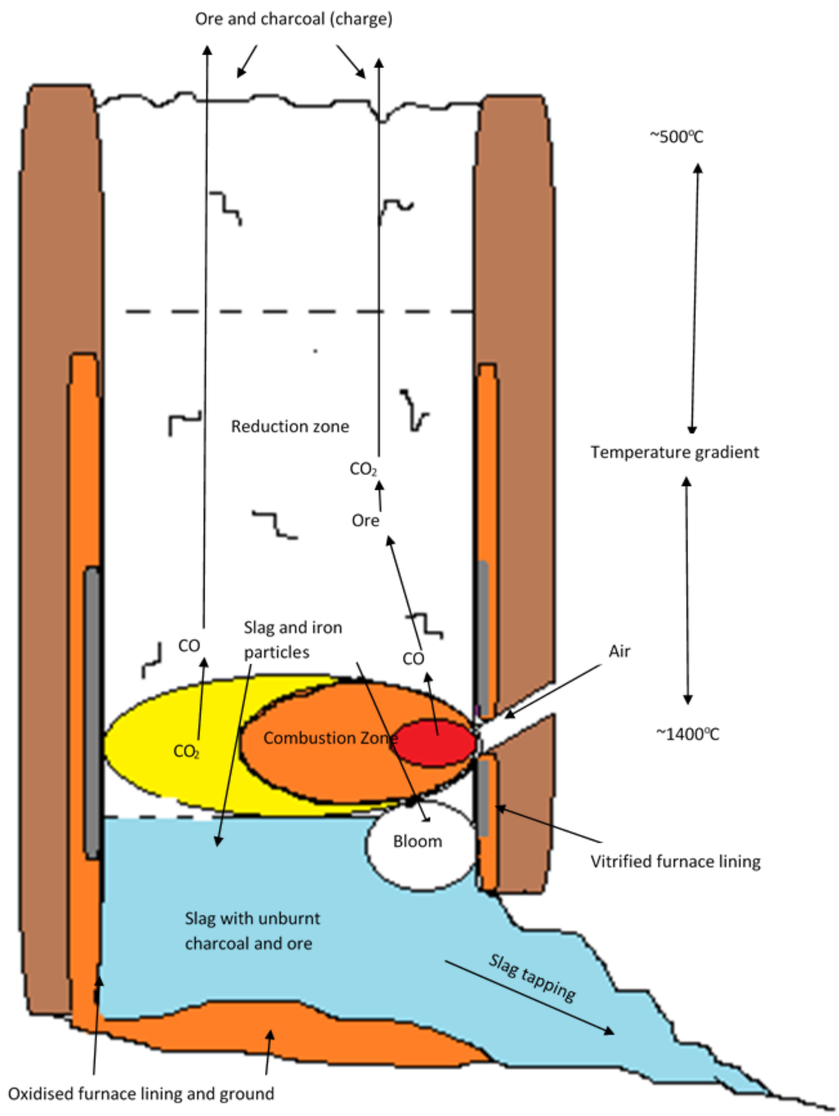


FIGURE 2.8: Schematic diagram of standardised direct smelting (bloomery) furnace

semi-closed environment, while having an air inlet towards the base, and an air outlet at the top for waste gas to escape and raw material, ore and charcoal, to be inserted. Some varieties that can occur include how the air is drawn into the furnace, forced draft through bellows or natural draft, as well as allowances for the removal of slag, tapping or non-tapping, and the physical building of the furnace including shape, size, and whether the superstructure is free standing or semi-buried. Early attempts were made by the likes of Coghlan (1977) to categorise different types of smelting furnaces and were mainly based on physical morphology. Since then others have tried to create classification systems for furnaces based on such aspects as how the slag is removed, air intake systems and again morphology (Martens, 1978; Pleiner, 1978; Serning, 1978; Tylecote, 1986). Cleere (1972) sets out a classification based primarily on whether the furnace has the ability to tap slag and then further sub-categories based on the morphology of the furnace. Due to the severe lack of superstructure of the iron producing furnaces in the archaeological record the only interpretations made about any furnaces discovered in this project will be based on the technological waste.

The process by which iron is smelted using the direct, or bloomery, process is strictly bound by chemistry and physics, although there is some amount of freedom within these restrictions. Therefore, for a successful smelt two basic processes have to be maintained. The chemical reduction of the iron ore to metallic iron and the formation and physical separation of the liquid slag. The furnace as a tool can help this be achieved by allowing for a high temperature to be maintained and for a carbon rich/oxygen lacking atmosphere to be created and maintained. This atmosphere is better understood as a CO/CO_2 ratio.

During a standard smelt, zones are created inside a furnace where different processes occur. Although these are probably not as clear cut as figure 2.8, there would need to be some degree of separation otherwise the smelt would not be successful.

Once the furnace was hot, by filling with charcoal and slowly raising the temperature, then it would have been continuously topped up with charge. This charge would have consisted of a mixture of charcoal and ore. Experimental studies have shown that a mixture by weight of 1:1 charcoal and ore to be the most effective (Pleiner, 2000 126).

As has already been seen, charcoal is important as fuel as when it burns it creates carbon dioxide (CO_2) and carbon monoxide (CO). This carbon monoxide is then the reagent in the reduction process to convert the ore into metallic iron, which means it is important to saturate the atmosphere within the reduction zone (fig2.8) with carbon monoxide.

$2C + O_2 \rightarrow 2CO$ (incomplete combustion - endothermic)

$C + O_2 \rightarrow CO_2$ (complete combustion - exothermic)

Through complete combustion the carbon is converted into carbon dioxide. This needs to occur within the furnace to obtain temperatures high enough to form a liquid slag, as this chemical process is exothermic which means heat is created. Incomplete combustion converts carbon to carbon monoxide which is needed for the reduction of ores to take place. This reaction is exothermic which means it is taking heat out of the furnace which needs to be counteracted by the complete combustion. At the tuyere, the atmosphere is almost pure carbon dioxide as this is where the air is being drawn or forced into the furnace.

This carbon dioxide then travels up through the furnace, as well as the high temperatures created. Once it meets the edge of the combustion zone it comes into contact and starts to penetrate through the charge which includes unburnt charcoal. Once the carbon dioxide and unburnt charcoal come into contact they react forming carbon monoxide which then creates a highly reducing atmosphere. Carbon monoxide can be created through incomplete combustion of the charcoal. However, this would only occur in a small area on the edge of the combustion zone where the oxygen levels are lower and would not be the main production of carbon monoxide (Rostocker and Bronson, 1990).

It can therefore been seen that how much air was supplied to the furnace was very important. If too much air enters the furnace then this would skew the CO/CO_2 ratio in favour of the carbon dioxide along with increasing the size of the combustion zone. This means the carbon dioxide would have less time to react with the unburnt charcoal leading to the skew in the ratio, along with reducing the amount of time the ore was in the reduction zone. However, if not enough air entered the furnace then a temperature may not be achieved that allows reduction to take place or more importantly the creation of liquid slag. These two cases could lead to a less efficient smelt or even in extreme circumstances a failed smelt (Pleiner, 2000).

There are three ways in which air can be supplied into the furnace. Natural draft is when the hot air rising through the furnace creates a pressure differential which draws air in through the air inlet, in the same way smoke is drawn away in a chimney. In order for this to occur however, a tall shaft type furnace would be needed. Twentieth century examples of this can be seen constructed by the Cewa of Malawi, whose furnaces reached eight feet in height and were natural draft (Avery, Van der Merwe, and Saitowitz, 1988). The second is forced draft. This is when air is forced into the furnace with a set of bellows. There are to date no examples of bellows that survive in the archaeological record of UK iron production sites. However, their use may be inferred by the discovery of tuyeres and clay nozzles on Roman iron working sites which are believed to be where the bellows were attached to the furnace (Cleere and Crossley, 1995 43). Moreover, there is picture representation of bellows on some Greek ceramics which also imply their existence (Cleere and Crossley, 1995 43). A piece of evidence from the site from Little Farningham Farm in the Weald may show that complex ceramic bellows would have been used that would allow for a constant stream of air to be produced (Cleere and Crossley, 1995 43-45). The third type is wind driven. These types of furnaces rely on a wind of consistent and sustained strength and have been identified in Sri Lanka, taking advantage of the monsoon wind (Juleff, 1998). However, this type of furnace has not yet been identified in Europe.

The temperature within a furnace varies greatly. In the combustion zone immediately around the air inlet, the temperature can reach around 1400^{o}C (Pleiner, 2000 p133). As distance increases from the air inlet, through the reduction zone, the temperature can drop to well below 500^{o}C at the furnace top (Powell et al., 2002 135).

Once the charge is placed in the opening of the furnace it slowly drops down through the furnace, undergoing various chemical reactions on the way. These chemical reactions are mostly dictated by temperature. Once the ore drops to an area where the temperature is in the region of 700 – 750^{o}C then two reactions occur. The haematite (Fe_2O_3) in the ore will begin to reduce to magnetite (Fe_3O_4) and the magnetite is then further reduced to wustite (FeO) (Pleiner, 2000 134-135). These two reactions also produce carbon dioxide which can either be converted to carbon monoxide, as has been seen, or continue rising though the furnace and escape at the top.

$$3Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2$$

$$Fe_3O_4 + CO \rightarrow 3FeO + CO_2$$

Due to these reactions occuring under non-equilibrium conditions, small grains are formed which are a mixture of iron ore, magnetite and wustite (Bray, 2006 51). Once these grains reach an area where the temperature is between 750^{o}C and 1100^{o}C (Bray, 2006 p51) then a reaction occurs in which the wustite is converted into metallic iron (Pleiner, 2000 135).

$$FeO + CO \rightarrow Fe + CO_2$$

In the areas where the temperature is above 1000^{o}C, the iron can be formed by direct contact between the magnetite or wustite and the carbon in the charcoal (Pleiner, 2000 p135).

$$Fe_3O_4 + 4C \rightarrow 3Fe + 4CO$$

$$FeO + C \rightarrow Fe + CO$$

When temperatures reach around 1135^{o}C the gangue or unwanted material in the ore begins to form liquid slag (Sim, 2012). The main constituent in the gangue is silicon dioxide (SiO_2) which binds with wustite to create fayalite

(Pleiner, 2000 136).

$$2FeO + SiO_2 \rightarrow Fe_2SiO_4$$

Fayalite, an iron silicate which is the most common dominant mineral in slag, is the ideal material to produce as it is created with the least amount of iron sacrificed, around 2:1 iron oxide to silicon dioxide (Schrufer-Kolb, 2004). However, this is not the only reaction that occurs as there is a multitude of other oxides and elements within the ore and other influences from the furnace lining and even the fuel. The slag then has to act as a sponge and soak up the products of all these other reactions to allow the metallic iron to be produced and isolated.

Once the gangue material in the ore liquefies, small 'shells' or networks of metallic iron are left. These, when they come in contact with each other, fuse together to form larger particles and then ultimately a spongy mass, the bloom, which tends to form at roughly the same level as the air inlet and often adheres to the wall of the furnace. The bloom is therefore a heterogeneous mixture of metallic iron, formed in its solid state, and liquid slag, which can be removed through smithing (Pleiner, 2000 135).

The metallic iron produced, although theoretically homogenous, is not. This is due to a process known as carburisation which occurs at temperatures over 900^{o}C and sees the iron absorbing carbon to make an iron-carbon alloy (Pleiner, 2000 135).

$$3Fe + 2CO \rightarrow Fe_3C + CO_2 \text{ (}3Fe\text{, ferrite. }Fe_3C\text{, cementite)}$$

This carburisation can have effects on the properties of the iron and if carbon content gets to between 0.1 to 2 % (by weight) then it can be considered steel

(Sim and Ridge, 2002 p117). A higher carbon content in iron can effect its properties making it much harder, yet more brittle. These properties were exploited by blacksmiths who would have recognised that this type of iron was much harder therefore better for creating edges on blades and cutting implements. There is evidence from the Roman period that the blacksmiths would have created metal sheets by layering softer wrought iron on harder high carbon steel to get the benefits of both types. These welded sheets would have then been used for such applications as *lorica segmentata*, which has been discovered at Vindolanda (Sim and Ridge, 2002 96). The side of the welded sheets with steel were facing out towards the enemy using its strength but the wrought iron also gave it flexibility, which means it was less likely to crack upon impact.

2.9 Smithing

It has been seen that the bloom produced in the smelting process is a heterogeneous mass of iron and slag. For the iron to be useable the slag must be removed and the iron consolidated into a solid mass or billet. This is done in the process known as bloom smithing. Once this billet of iron has been produced it can then be formed into bars of iron of various sizes, depending on the artefact that is going to be produced, in a process known as bar smithing. Once the bars of iron are produced then they are ready for a skilled smith to turn them into various artefacts.

The objective of bloom smithing is to remove all the slag inclusions and weld the iron into a solid mass. This is achieved by heating the bloom to such a temperature that the slag is fluid enough that when hammered it can be expelled but not so fluid as to flow out freely otherwise this would leave voids within the bloom causing it to split into pieces upon hammering (Sim, 1998 11-12). Through experimental recreation it has been seen that temperatures between 1000^{o}C and 1100^{o}C are necessary for bloom smithing (Sim, 1998 p26). Great care has to be taken when hammering as it can be difficult to obtain a yield of 25% of the original bloom weight due to pieces of the boom fracturing off. However, with constraint of specialised tongs that do not allow the fractured material to fall off, a yield closer to 90% by weight is possible (Sim, 2012 57). The result of this bloom smithing would have been a billet of consolidated iron.

This billet however would have often been too large and cumbersome to rework into a finished product and would have taken a lot of time and fuel to reheat to the correct temperatures. This can be seen in an experiment by Sim (1998) where it took one hour to heat a 5.8kg billet to 800^{o}C. It is therefore conceivable that these larger billets would have been forged down into smaller billets of varying size and cross section depending on the object to be made (Sim, 2012 21).

Once the bar had been produced then a finished object could be made. The amount and range of items made of iron in the Roman era was huge with almost all everyday activities relying on the use of iron. Many artefacts such as nails could be made in high volume by semi-skilled workers but items such as weapons and tools needed an experienced smith to make them (Sim, 2012

22).

Throughout all of these smithing processes a hearth would have been used to heat the iron. Unlike the furnace, where an oxygen starved atmosphere was needed and had to be maintained, the only aim of the hearth is to be able to create a temperature high enough to soften the iron to allow smithing to take place. There were no real provisions needed and a piece of iron could be reheated in a pile of charcoal with bellows, this being an oxygen-rich atmosphere (Pleiner, 2000 216). If a hearth was formed in this way then the remains could be difficult to find in the archaeological record with the only evidence being signs of burning on the earth or slight depressions. However, with such a complex system to get from ore to bar iron it seems inconceivable that the smith would just have a pile of coal on the ground and a better designed system would have been used. The hearth would have had to have been big enough that the entire bloom could fit in it and be covered in fuel, meaning it would be heated more efficiently and not become oxidised (Sim, 1998 19). Moreover, as the main aim of bloom smithing is to remove the slag then the hearth would have had to have been deep enough to allow slag to pool and not come back into contact with the bloom or be able to be tapped away (Sim, 1998 p19). Also thick walls to a hearth and a blow hole would prevent unnecessary heat loss and allow greater control of air flow (Bray, 2006 63). For these reasons it would be likely that the hearths would have had some form of superstructure and also have been raised off of the ground to make it easier for the smith, meaning he did not have to bend over so much. There is pictorial evidence of raised hearth, including an image from Pompeii (Sim, 2012).

Smithing can leave other evidence in the archaeological record in the form of hammerscale. Flake hammerscale is small fragments of oxide or silicate skin that are displaced due to the mechanical forces of hammering and spheroidal hammerscale is created from the solidification of small droplets of slag as it is expelled from the iron (Starley, 1995).

2.10 Iron production in the archaeological record

This section will set out how the remains of the iron production process survive in the archaeological record, with a focus on smelting and their associated sites, as this is the main research area of this project.

2.10.1 Mining

Mining has the potential to create large volumes of waste. A lot of this waste would be undiagnostic as it would simply be the natural soil and rock which is excavated during mining. However, deposits of the natural soil and rock should be examined carefully as there may have been a form of screening at the mining site. This is due to the fact that if the mining site was a relatively large distance from the smelting site then it would have been more efficient to only move the sorted ore that is to be roasted and smelted than moving everything and then sorting. There is potential though for archaeological evidence to enter into this waste deposits. The first example is the charcoal and remains of firesetting. This could include large amounts of charcoal which would allow

FIGURE 2.9: LIDaR map of minepits in St Leonard's Forest, Sussex (Blandford, 2013)

for radiocarbon dating to be undertaken. Moreover, if this evidence is in stratified layers or what appears to be multiple phases then multiple radiocarbon dates could be taken to build up an understanding of the time in which the site was in use (Bray, 2006 40).

In any of the waste deposits associated with mining there is the potential for discarded or accidental burying of tools or anything associated with the workers, for example at Great Orme where bone tools and hammer stones were discovered in the mine waste dating to the bronze age (Timberlake, 2003). There has to date been no large scale study of the iron ore mining remains from the Roman period so this evidence is not as understood as it has the potential to be.

In the wider landscape of the Weald mining leaves a clear sign by the open pits left behind. As has been previously discusses an example from Petley Wood has been positively dated to the Roman period (Worssam, 1995), and Figure 2.7 shows an individual flooded minepit in Forewood, Crowhurst. However, these are not unique features in the landscape, but often found in groups as the ore deposit is chased and utilised. This can be seen in St Leonard's Forest where a high number can be seen via LIDaR (Fig2.9). Even though these are believed to date to the 16^{th} and 17^{th} century (Blandford, 2013). Throughout the lands around the village of Brede there have been a number of minepits identified . A number of minepits were identified ranging in diameter size from 30m to 2m. Within a few kilometres of these minepits is a blast furnace site and six known bloomeries(Turgoose, 2017). This then raises another issue with associating minepits with their contemporary production sites. This information could assist in dating the minepit as well as inform on the scale.

2.10.2 Ore sorting and roasting

The processes involved in ore sorting and roasting can leave behind a large and varied amount of evidence in the archaeological record. This can help archaeologists further understand the processes that were undertaken on an iron production site, and extrapolate how these decisions could have influenced the wider industry.

The ore itself is one piece of evidence that can be discarded on an archaeological site for a number of reasons. Raw ores and natural rock may be discarded on sites as they are screened and deemed as low grade, therefore, not worth roasting or not of use and rejected. Moreover, evidence from Ridlington, Rutland, showed ore with a low iron content was roasted then discarded which could show it was thought to be good enough quality to roast but then deemed not good enough to smelt (Schrufer-Kolb, 2004 83). The most common form of ore found on sites is roasted ore fines. These are small particles of roasted ore that are by-products of the roasting and crushing processes (HMSdatasheet5).

Another piece of evidence left behind by ore roasting in the archaeological record is the area or structure in which it was roasted. These can vary greatly in morphology and remains, and could be evident in the archaeological record at Blacklake Wood in Exmoor and Bardown in the Weald. In Blacklake Wood an area was discovered that showed high levels of oxidation, red colouring of the earth, with two patches within this area showing even more intense burning, purple-black coloured earth. This area also had a large amount of magnetic material within it and a small pile of unroasted ore next to it, presumably ready to roast (Bray, 2006 p47). Whereas at Bardown in the Weald, a permanent pit constructed of stone and lined with clay measuring 2.5m in length, 0.8m in width and 0.2m in depth was discovered and has been convincingly linked to ore roasting though experimental reconstruction (Cleere and Crossley, 1995 35).

2.10.3 Charcoal

Charcoal is a major material in every stage of iron production. It is then not a surprise that it exists in large amounts in the archaeological record, being most evident on iron production sites incorporated in the waste deposits. Although most of this charcoal is undiagnostic fines, the stratigraphic layers in which the material occurs could help in the understanding of how each stage was undertaken on site and whether there was any type of cyclical working. Also if larger pieces of charcoal were to survive then analysis could inform as to the species and type of wood being used, age of the wood, and even the season of coppicing. By conjoining this with the stratigraphic layers in which it is deposited could give further information as to wood selection for specific processes, season of production and cyclical processes.

2.10.4 Smelting

The process of smelting iron will leave an abundance of evidence in the archaeological record. This evidence can include furnace remains (in situ or displaced), partly smelted ore and charcoal mixture, slag, and in very rare circumstances bloom iron.

The remains of in situ furnaces can show in great detail the effects that firing has on the clay walls. The internal wall surface of the furnace, where the temperature is reaching its highest, could have become vitrified. Vitrification is the process in which high temperatures within the furnace melt and transform the silica in the clay to a ’glass’ silicate. The higher the temperature, and the longer the heat is present for, the more advanced the vitrification could become. Therefore, this can be an indication as to the temperature and duration of the smelt that occurred when the vitrified surface was produced. Moreover, this can be experimentally recreated so a greater understanding can be gained of not only the temperature at the point of vitrification but also throughout the rest of the furnace (Craddock, 1995 16-17). Vitrified clay is a more durable material than un-vitrified clay, potentially allowing for better preservation of the size and shape of the 'footprint' of the furnace, or features within. More evidence that can be taken from in situ furnaces is the colour of the un-vitrified clay. The furnace wall that encases the reduction zone would be coloured a deep grey due to the reducing effect on the clay. As we move through the wall from inside to outside the colour would change to a more red, orange or yellow colour due to temperatures decreasing and conditions becoming more oxidative and less reducing. Certain inferences can be taken from the vitrification and colouring of the clay. For example, the grey reduced clay and vitrification would be a sign that the structure was, with a high degree of certainty, a smelting furnace as no other processes need such a highly reducing environment or reach such high temperatures. Also, the position of the vitrification on the furnace wall could indicate the location of the air inlet as this is where the temperature would have been at its highest and could be backed up with the colour being red, orange or yellow showing the highly oxidating atmosphere which would have been present around the air inlet. In some cases, successive layers of colour can be seen built up which could be a sign of repair and reuse of the furnace.

This colouring effect would not only have been present in the clay of the furnace wall but also in the ground the furnace is built on or in. This is an advantage as when no furnace superstructure has survived the same diagnostic elements may still be found.

As the main portion of the furnace is built above ground it is prone to weathering and damage. Damage would have occurred from the heating and cooling of the furnace and potentially with the removal of the bloom. For these reasons, furnaces would have had a timespan in which they worked efficiently and were structurally sound. Once they reached the end of this time, they would have then been abandoned and a new furnace constructed in a different location, or the used furnace deconstructed so a new furnace could be built in the same position. Therefore, the superstructure of furnaces are rare in the archaeological record, but do exist as debris within the waste deposits and can potentially give archaeologists information about the furnace itself. If the discarded pieces of furnace are large enough then a circumference could be estimated. Moreover, by looking at the stratigraphic build up within the waste deposits it may be possible to estimate when in the cycle the furnaces are renewed and after how many smelts.

Another piece of evidence that is found on iron production sites are tuyeres. Tuyeres are purpose-built apparatus that fit into the furnace and act as air inlets. This can either be to enable a bellows to be attached while being protected from the high temperatures or just act as an air inlet for natural draught furnaces. The construction of the tuyere includes a pre-firing step in which to bake and harden it in order to increase the durability, also allowing for a standardised design. An excellent example of where tuyeres have been used for natural draught furnace is in the study by (Juleff, 1998) in Sri Lanka, and have also been identified in large quantities in the iron production site at Meroe, Sudan (Humphris and Carey, 2016). An advantage of having tuyeres is that if the slag builds up and they become blocked, or are broken, they can be easily removed and replaced without too much damage to the furnace, prolonging its life (Pleiner, 2000 196). Due to the tuyere being situated in the hottest part of the furnace it would have been subject to high levels of oxidation. Therefore, tuyeres that are found would be expected to have a red to yellow colouring and potentially high levels of vitrification. It is often only the tips of the tuyere that survive due to this high level of heating which hardens the clay and makes it more resilient to degradation (Pleiner, 2000 196). Tuyeres for furnaces and hearths often are the same in morphology, which means there is no way to distinguish between them (Pleiner, 2000 196). If a tuyere is found in the waste deposits it is then not possible to say definitely where it came from. Throughout the Weald it is unclear if tuyeres are being used in the Roman period, but it is the opinion of this project that they are not. They are not found throughout Wealden sites in the quantities seen on site in Sri Lanka (Juleff, 1998) or Sudan (Humphris and Carey, 2016). Moreover, the artefacts that have been identified as tuyeres in the Weald, including the 'double tyuere' discussed by Cleere (1963) has been shown experimentally by Prus (2011) to most likely not represent a tuyere and therefore be wrongly identified.

Slag is the most ubiquitous material left on an iron production site and tends to remain in the archaeological record. There are some cases, such as Beauport Park in the Weald where slag was removed for road metalling in the 19th century (Cleere and Crossley, 1995 72). Although it is often present in large amounts it is not homogenous and displays large variation in morphology and texture. A number of classification systems for slag have been developed which are summarised well in Schrufer-Kolb (2004) tables 3 and 9.

One of the greatest influences on the morphology of the slag is how it was produced and removed from the furnace. As the smelt is happening the slag will form as a liquid pool in the bottom of the furnace. In some of the earliest furnaces no provision was made to remove this slag, therefore it built up to a point where it blocked the air inlet and smelting had to stop. Two techniques were developed to try to counteract this, as can be seen in Cleere (1972). One of these techniques was to dig a pit beneath the furnace which meant the slag had a larger area to flow into and fill up allowing a longer smelt before the liquid slag reached the air inlet, blocking it and stopping the smelt. These slag-pit furnaces were common throughout Europe in the Iron Age and Roman era and could produce blocks of slag up to 450kg (Pleiner, 2000 149-163). These blocks of slag, 'furnace bottoms', tend to be very dense and will conform to the shape of the pit that has been dug out to collect it (Schrufer-Kolb, 2004 p10). There is also furnace slag which is very similar to furnace bottoms as it shows no sign of tapping therefore must have cooled and solidified in the furnace. It is also dense but can have imprints and inclusions of charcoal and ore and possible slag runners or drops formed on its upper surface (Schrufer-Kolb, 2004 p10).

The other technique was to create a small opening in the furnace that allowed the liquid slag to flow freely out of the furnace which means it would not fill to the point where the air inlet was blocked. Slag produced from this type of furnace is very distinctive with a ropey or worm-like texture on the upper surface created by the viscous slag flowing and solidifying. The base often preserves the texture of the surface upon which it flowed and solidified. This type of slag is rarely discovered as large slag cakes, but when it is, such as at Clatworthy Reservoir on Exmoor, it can give an understanding as to how much slag built up in the furnace before tapping, allowing an estimation as to the minimum amount of iron produced (Bray, 2006 57). However, generally this type of slag is often found as smaller fragmented pieces. This can still give archaeologists useful information as it often contains bubbles whose number and size are influenced by the rate at which it cooled with a higher number of larger bubbles being an indication of rapid cooling (Bray, 2006 57). Also, as slag tends to be discarded into the waste deposits, the way and amounts in which it is deposited and the stratigraphic deposits surrounding it can lead on to many other inferences such as the yield of the site and the cyclical nature of processes (Humphris and Carey, 2016).

Tap slag, furnace bottoms and furnace slag are the three major types of slag present on smelting sites and although other slags may be produced these are often non-uniform in a nature therefore must be analysed on a case by case basis (Bray, 2006 59).

2.10.5 Smithing

Smithing, just like smelting, can leave its own unique evidence in the archaeological record. The most common of the evidence left is smithing slag. As the bloom is heated for smithing the slag drops off into the bottom of the hearth, combining with fuel, ash, and small pieces of iron to form hearth bottoms (Schrufer-Kolb, 2004 10-11). These hearth bottoms can build up to a point where they block the air inlet to the hearth, stopping it from working (Sim, 1998 19). Therefore, hearths would have been cleaned regularly and slag discarded adding another layer of information to the waste deposits, if the two processes are occurring on the same site. Smithing slag can also take on a number of morphologies depending on how it is expelled from the bloom. As we have seen it can simply run out in the hearth but it can also be forced out mechanically by hammering, forming spherical slag, all of which would create uniquely shaped pieces of slag.

Another distinctive piece of evidence left in the archaeological record by smithing is hammerscale. Hammerscale is produced when the oxidised surface of the iron is mechanically broken off, by hammering for example, and is usually in the form of small fishscale like flakes (HMSdatasheet). This can be deposited in the waste deposits or elsewhere, such as trampled into the floor, and is excellent evidence of smithing. Care must be taken however that it is not mistaken for roasted ore, which is also magnetic like hammerscale or slag shells, which are flaky in nature but on closer analysis are a different shape (Schrufer-Kolb, 2004 11).

If smithing is undertaken in a set area either intensely or for a long period of time then these waste products, hammerscale and slag, can build up on the floor around the anvil. These can then get trodden down and form an extremely hard concretion called a smithing floor. This type of floor can potentially show the layout of the smith's workshop as the floor would only form thickly where it is open therefore leaving areas clear where the hearth, anvil and storage would have been (Bray, 2006 65). A very high quality example of a smithing floor was found at Sharracombe Ford on Exmoor, where the floor reached a depth of up to 0.4m thick with the thickest deposits around two sockets which are believed to have held the anvil (Bray, 2006 111). However, care must be taken as evidence of this strength is not very common on Roman iron production sites which opens the debate as to whether there was a standard smithing practice or if smithing even took place on the site. Moreover, due to there being bloomsmithing and smithing to make product adds a further level to the debate.

2.11 Use of Geo-prospection for the investigation of iron production sites

Geo-prospection is widely used throughout archaeology in both the academic and commercial sectors to investigate sites and their features in a non-invasive way. The techniques and there uses are clearly set out in a number of standard textbooks such as Gaffney and Gater (2003), Clark (1990) and Reynolds (2011), which will be set out in more depth in chapter 3.

The main and well-developed method for the use of these survey techniques throughout archaeology has been to produce two dimensional birds-eye view plans of a site in order to identify feature for targeted investigation, however there has been substantially less development in the use of these surveys to investigate metallurgical sites. An overview will be made here of the key literature in the development of geoprospection techniques on metallurgical sites.

Many studies have shown how magnetic surveys, such as magnetometry, can be used to identify magnetic signatures on metallurgical sites (Vernon et al

1998, Crew 2002, Crew et al 2002, Powell et al 2002, Smekalova and Voss 2002, Walach et al 2011, Carey and Juleff 2013, Humphris and Carey 16). However, many of these studies show the major issue with this type of survey which is that with such high magnetism on a metallurgical site, particularly iron production, features can become obscured or lost entirely. For wider site interpretation magnetic survey techniques do work well as shown by Carey and Juleff 13, Humphris and Carey (2016) as well as a number of surveys local to the Weald including those conducted by a local society the Hastings Area Archaeological Research Group (HAARG). However, this survey type does not allow for depth or volume calculations of features such as waste deposits.

A number of studies have started to develop methods to answer the research question of calculating the depth and volume of waste deposits on metallurgical sites. However, this is an area that needs more development in the future.

Florsch et al (2011 and 2012) is one of the most notable studies to use induced polarisation to calculate the mass and volume of the waste deposits at the site of Castel-Minier, France. This study covers laboratory calibrations of the survey type, in field surveys and large scale excavations to ground truth the survey results. Meyer et al (2007) also use induced polarisation to great affect when assessing the depth of slag heaps in Munigua, Spain, along with comparable earth resistivity tomography surveys to assess the depth of waste deposits and other features such as slag filled pits. Ullrich et al (2009) also modelled waste deposits using both earth resistivity tomography and induced polarisation at Munigua, Spain, as well as Ain Al Hajer, Morocco.

A number of surveys have taken place on iron production sites in Sudan. One by Ullrich et al (2015) identified waste deposits due to differing resistivity. Most notable though, is the study conducted by Humphris and Carey (2016) at Meroe, where an earth resistivity tomography was used alongside GIS modelling, mass density analysis and volumetric data. This study shows the ability of ERT to allow for the interpretation of features within a waste deposit as well as its methodological use in a well-rounded investigation of this type of deposit.

2.12 Conclusion

It can be seen that the Weald, as defined by its geology and environment, has played a key role throughout the history of Britain as an important centre of iron production, with the iron produced being used both locally and on a global scale, creating weapons for armies and every-day items for the local population.

The smelting of iron leaves a large amount of evidence in the archaeological record and across landscapes. Some remains are more evident, such as waste deposits and mining, as these change the landscape and can be easily identified without needing to excavate. Others such as the furnaces themselves need to be investigated through a number of different survey and excavation techniques to identify, which means they are less represented. Moreover, these smaller pieces of evidence, such as furnaces, are far more prone to destruction through modern day agricultural practices, which means they may be removed from the archaeological record before being discovered.

Research into metallurgy has taken many different routes and within these there has been a large number of studies completed. Some of this research has taken a very narrow look at the processes involved (Craddock, 1995; Pleiner, 2000; Rostocker and Bronson, 1990; Tylecote, 1986, 1987, 1992), while others have taken a wider view of the research looking at the industry within landscapes (Bray, 2006; Cleere and Crossley, 1995; Juleff, 1998; Schrufer-Kolb, 2004). With technology becoming more and more ingrained within the archaeological framework, studies are now being produced that look at the details of the individual sites to inform on the large impact of the industry on the landscape (Florsch et al., 2011; Humphris and Carey, 2016; Ullrich, Wolf, and Kaufmann, 2014).

We can see from the information presented within this chapter that the process of smelting from ore to usable iron exists within a very narrow scientific framework that does not allow for much variation before the smelt would fail. However, around this framework there does seem to be the allowance of variation, including the different ores that could be used as well as the differing morphologies of the furnaces themselves.

The skill of smelting iron was not a simple task that could be carried out by a single practitioner. The process would have involved a skilled and knowledgeable group to perform a number of tasks from identifying the correct ore that was rich enough in iron minerals, to being able to understand the workings of the furnace and the parameters that needed to be maintained without the use of modern day scientific investigation and understanding. Both of these would be crucial to accomplish a smelt and retrieve enough metallic iron to make the process economically viable.

3 Approaches of Investigation

This chapter will set out the approaches used for the investigation of iron production sites in this project. How the case studies for this project were identified and the partnerships that occurred within these will be discussed. The geo-prospection techniques that are used throughout this project will be set out, with information given on their developmental history, the scientific principles the techniques are based on, what anomalies are expected to be identified, how this is applicable to the investigation of iron production sites, and what specific apparatus will be used in this project, as well as how this will be deployed in the field. The approaches to excavation will then be discussed, looking at how and why the deposits should be excavated to meet the aims of this project, the choice of trench positioning, how and what material would be collected for post excavation analysis, and a standard methodological approach used. Finally the analysis of material will be set out with a discussion on quantification, characterisation, and classification.

3.1 Site Identification

Research into iron production in the Weald has been established and sustained over many decades, including the practice of discovery and identification of sites. As a result a large database of evidence has been accumulated by WIRG, which is publicly available online (WIRG, 2019). This database allows for rapid searches of known sites via a number of different queries including date, area, technology, finds etc. This database provided the primary source in this project for identifying sites for further investigation. First the database was searched for sites of known Roman date, of which there are 135 categorised. These sites were then categorised according to the information available on the database as to whether they could be potential sites for further research. This included previous research, certainty of dating evidence and geographical location. This geographical location allowed for the site to be identified on a satellite map to understand the site setting and terrain, and if this would allow suitable investigation using geo-prospection surveys and excavation. Once sites were identified that were deemed suitable for further research, an attempt was made to contact landowners via email or phone. If landowners could not be contacted, an attempt was made in the field. Once permission was obtained the site was walked to understand the reality of the land use and feasibility for investigation. If public footpaths ran through the site, as was the case with a number, then attempts were still made to locate and gain permission from the landowner, but if not then public footpaths were adhered to. Due to transport issues nine sites were initially chosen to be visited in the field, within an area in the southeast of the Weald, deemed viable for the first season of fieldwork. These were; Chitcombe, Footland Farm, Oakland Park, Crowhurst Park, Forewood, Bynes Farm, Pepperingeye, Church Farm Field, and Church Field Old Place. Out of these nine sites, the landowners of only two, Chitcombe and Crowhurst Park, could be contacted for permission to explore the sites.

However, Footland Farm, Oakland Park, Forewood, Church Farm Field, and Church Field Old Place all had public footpaths on, so the sites could be explored. Through a conversation with the landowner at Chitcombe it became known that the Hastings Area Archaeological Research Group (HAARG) had began research on the site and had fieldwork planned. HAARG were then approached by the author, and an agreement reached for this project to join theirs. The site of Chitcombe then became the first case study in this project that will be further discussed in Chapter 4 and 5. Throughout this whole process, continuous discussion were held with members of WIRG as they hold a vast local knowledge of sites and landowners helping to streamline the process. It is through these discussions the second case study was identified. Jeremy Hodgkinson, from WIRG, had a contact at Standen, East Grinstead, in the northwest of the Weald who was interested in the Roman iron production site on their land being investigated. Introductions were made between the author and the land owner by Jeremy Hodgkinson and a project developed forming the second case study (Chapter 6 and 7).

3.2 Geo-prospection surveys

There are a number of different geo-prospection techniques available to investigate archaeological sites. Each technique utilises a different scientific principle in order to detect different types of anomalies. Many of these techniques were designed and used in the geological and Earth science industry before being adapted for use in archaeology. These techniques include resistivity, magnetometry, electromagnetic (EM), metal detecting, ground penetrating radar

(GPR), seismic, microgravity, induced polarisation (IP), and thermal imaging. Some of these techniques also include a number of sub-categories using the same theoretical framework, but using different physical arrays. An example of this is within resistivity surveys where a twin probe array, the standard used in archaeology,will give a two-dimensional plan of the resistance across a site, whereas Earth resistivity tomography uses the same scientific principle but gives a vertical two-dimensional image of the resistance along a single traverse. The following sections will set out, the scientific frameworks within which the systems, selected for use in this project, operate and detect anomalies. This look at the scientific framework is in-depth for an archaeological thesis. However, it is believed that a more comprehensive understanding of how the technique works will create a more accurate understanding and interpretation of the data. Moreover, although some of the techniques are common-place in archaeology, such as magnetometry, some such as Electromagnetic surveys and Induced Polarisation are not, so an understanding of the techniques are needed in order to validate their application to this project and archaeology in general.

3.2.1 Magnetometry/Gradiometry

Magnetometry is a method by which the apparatus detects small anomalies within the Earth's magnetic field caused by features within the Earth's near surface at a localised and discrete level (Gaffney and Gater, 2003).

Iron constitutes around 6% of the Earth's crust and occurs spread through the geology and soils in a variety of different chemical compounds. Due to anthropogenic activity, these iron-rich compounds can be redistributed and altered into more magnetic forms. This creates anomalies in the Earth's magnetic field at a localised level which can be detected (Clark, 1990).

The study of this technique started in the 1600's with the investigation of the Earth's magnetic field by physicist William Gilbert. By 1640 measurements of changes in the Earth's magnetic field were being used to detect deposits of iron ore. By 1870 a basic instrument had been created capable of quick and accurate detection of changes in the magnetic field. Throughout the 20^{th} century many advances were made in this field leading to machines that were of higher accuracy and faster to deploy and use in the field. This included machines such as the optical absorption magnetometer which could be used in airborne surveys, and the magnetic gradiometer which not only the detects the changes in the Earth's magnetic field but also the gradient between two sensors, gaining a much higher resolution in demarcating targets (Reynolds, 2011 83).

There are two main types of magnetism that exist, induced (diamagnetism or paramagnetism) or permanent/remnant (ferri- and ferro- magnetism). Permanent magnetism is the measurable magnetic intensity maintained by internal field strength even after an applied field has been removed. Induced magnetism is when the magnetism is caused by an applied field. Magnetic susceptibility is a measurement of how susceptible a material is to becoming magnetised by an external field and can be negative as well as positive. Often both of these exist together within a material and depending on their individual strengths and orientation, have an effect on one another (Griffiths, 1999 255).

Quantum mechanics states that around atoms two electrons can exist in the same electron shell as long as they spin in opposite directions, these are called paired electrons. This is due to the magnetic moments of each electron cancelling each other out. If a material has all its electron shells complete with paired electrons, for example copper, gold or bismuth, then this is known as diamagnetic. When a magnetic field is applied to these materials it causes the electrons to orbit in such a way that a magnetic field is created that opposes that being applied. This leads to a cancelling out and/or repelling of the magnetic field, creating a negative susceptibility. However, if a material has an incomplete electron shell, which is known as paramagnetic and includes for example aluminium or platinum, then the magnetism of the electrons aligns with the induced magnetic field, creating a positive susceptibility. This positive susceptibility can be affected by temperature according to the Curie-Weiss law (Griffiths, 1999).

The Curie temperature, above which thermoremanence occurs, is a point at which the alignment of magnetic moments of the electrons and crystalline structure decompose, due to increased entropy, leading to random orientation. The temperature of this point changes depending on the material. When cooled back below the Curie temperature, the magnetic moments and crystalline structure will realign to match an external magnetic field, in archaeological cases this will be the Earth's magnetic field (Clark, 1990; Reynolds, 2011). This law affects ferromagnetic materials; for example for haematite the Curie point is 675^{o}C and for magnetite is 565^{o}C (Clark, 1990). Ferromagnetic materials consist of atoms with unpaired electrons. These atoms are strongly attracted to each other due to these unpaired electrons and the magnetic forces they create. These moments can then either become aligned in a parallel orientation or an anti-parallel orientation, which is known as anti-ferromagnetic. Ferromagnetic materials have a high susceptibility and permanent magnetism. Anti-ferromagnetic material, which includes haematite, should be magnetically void due to the anti-parallel orientation cancelling each other out. However, there are often discrepancies in the crystalline structure which allows for a nett moment to occur, this is known as parasitic (anti)ferromagnetism. Ferrimagnetic materials are similar to anti-ferromagnetic materials in the fact that they are in anti-parallel alignment. However, in ferrimagnetic materials one of the direction of moments is stronger that the other giving a net magnetism that can exist without an external field. The effect of thermoremanence is permanent within the object until it is heated over the Curie point again (Griffiths, 1999). The level of magnetism has to be kept in perspective as a strong magnetic field created by reaching the Curie point could be somewhere in the region of 500nT and other forms of archaeological features could register as low as 1nT. However, the Earth's magnetic field in Britain is usually between 50000nT and 60000nT (Clark, 1990). An object is seen to have magnetic susceptibility when it becomes magnetised when placed within a magnetic field. A material is seen to be more magnetically susceptible the more highly it becomes magnetised in an inducing field. The effect is only temporary, and as soon as the magnetic field is removed the material will become demagnetised. With the Earth having its own magnetic field it means that magnetic susceptibility is always 'on', meaning that this magnetism can be detected, known as passive detection, or a separate magnetic field can be introduced, and this magnetism detected, and is known as active detection (Clark, 1990).

FIGURE 3.1: Bartington GRAD601 twin-probe

The instrument being used in this project for the magnetometer surveys is the Bartington GRAD601 (fig 3.1). There are a number of magnetic detection instruments available on the market, but the Bartington GRAD601 was the instrument available for this project and will be discussed in more detail later in this section. A further type of magnetic survey was used as part of the Electromagnetic surveys and will be discussed separately later in this chapter. The GRAD601 is a Fluxgate gradiometer, the Fluxgate referring to the type of magnetometer sensor and the gradiometer referring to the specific layout of these sensors in relation to each other.

A Fluxgate gradiometer, consists of two parallel cores of ferromagnetic material. Around these cores are wrapped a primary coil in series and a secondary coil also in series but in the opposite directions to the primary coil (FIG 3.2). An

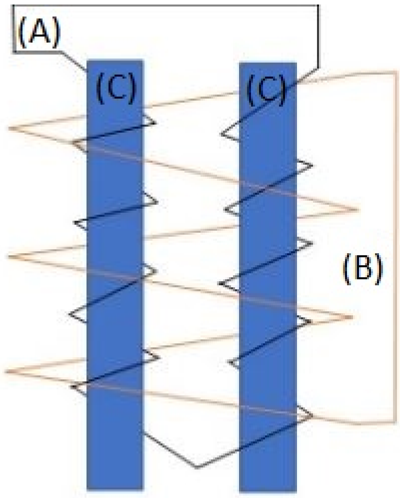


FIGURE 3.2: Fluxgate Magnetometer: (A) is the Primary Coil, (B) is the Secondary Coil, and (C) are the Magnetic Cores.

alternating current is passed through the primary coil which causes the ferromagnetic cores to become magnetically saturated every half cycle. This generated magnetic field causes a voltage within the secondary coil. Due to the coils running in opposite direction they have opposite polarities which means that their collective sum is zero. However, if an external magnetic field is present, for example the Earth's, then the saturation of the cores will occur earlier, shifting the secondary voltage and creating a measurable response. The stronger the external field the larger the response will be.

A gradiometer is a device that measures the difference between two identical magnetometers that are separated by a small static distance. These sensors are usually positioned in a vertical formation with one sensor near to the ground. Both these sensors are influenced by the Earth's magnetic field. However, the sensor near to the ground is also influenced by magnetic features within the

Earth. By taking both sensors and subtracting the results from the top sensor away from the lower sensor, all background magnetic interference is removed allowing for isolation of the data caused by the features within the near surface.

This technique detects any feature that contains chemicals that carry a magnetic field, mostly iron oxides, magnetite, haematite and maghaemite. This includes pieces of ferrous metals, burnt clay in kilns or furnaces and changes in magnetic chemicals due to ditches and pits, detrital or post-depositional remnant magnetism (Clark, 1990).

The magnetometer survey was chosen for the investigation of iron production sites in this project for a number of reasons. The use of this technique in archaeology is ubiquitous meaning there is reference data available to assist with interpretation. Also due to this high use across archaeology the equipment is easily available for the technique to be replicated in the future. Due to the site being used for iron production there is an assumption that there will be an increased amount of magnetic material on the site which is readily detected using this technique. Magnetometry is also an adequate technique for detecting other archaeological features including areas of burning or ditches and pits which will allow for the wider understanding of the site. A possible issue may arise with this survey technique that is specific to the type of sites being investigated in this project. With such a high level of magnetism spread over the Roman iron production sites it may become difficult to calibrate the machine and features may become obscured. Due to the high magnetic potential of these type of sites the limit will be set to 1000nT rather than the standard

100nT giving clearer results of higher magnetic areas, with the hope there will be less obscuring of features. Due to the flexibility of the use of the use in the field particularly the Bartington GRAD601, grid sizes and data readings will be changed in the field according the conditions of the area being surveyed, for example open field or woodland.

The data collected during the magnetometer surveys will be post processed on the computer using the programme Geoplot, which interprets the data into a form of heat-map (example data ap A.2.1).

3.2.2 Earth Resistivity Tomography

Earth Resistivity Tomography is a technique that measures the change in resistivity within the near Earth by passing a current, through the ground, between two electrodes. The use of measuring electrical resistivity as a survey technique started in the early 1900's. However, this technique really came into its own from the 1970's on-wards with the introduction of computers for quicker and higher-powered data processing. This technique, like most others, started its life in the field of geology, prospecting for groundwater, subsurface cavities, geological faults etc, but is now used in a variety of fields including archaeology (Reynolds, 2011).

Electrical resistivity can be measured by a variety of techniques including ground contact techniques, that will be discussed in this section, and electromagnetic induction, which will be discussed in under Electromagnetic survey later in this chapter. At its most basic principle, resistivity is a method in which electrical currents are passed into the Earth and the change in those currents is measured (Gaffney and Gater, 2003). Resistivity can be used in the field in two ways. One is to measure the resistivity of a vertical sections known as vertical electrical sounding (VES). The second is to investigate horizontal profiles, known as constant separation traversing (CST). Both can be joined to obtain a measurement of both vertical and horizontal information, known as subsurface imaging (SSI) or electrical resistivity tomography (ERT). This technique, when the two are used together, offers the ability to produce high resolution data of the near surface, an advantage in archaeology (Reynolds, 2011).

If a cube of homogeneous material with side length L has a current (I) passed through it, the material inside the cube may resist the current causing a potential difference (V) on opposing faces of the cube. The resistance (R) can be measured according to Ohm's law $R = \frac{V}{I}$. Resistance is not seen as a good measurement, as it is influenced by the shape and size of the deposit being measured which can be seen in the equation $R = \rho \frac{L}{A}$, where L is the length, A is the cross-sectional area, and ρ the resistivity. Resistivity (ρ) is therefore the preferred measurement as this is intrinsic to the material, hence not influenced by size and shape. It can be defined by the equation $\rho = \frac{VA}{IL}$ which can be simplified to $\rho = R\frac{A}{L}$. Resistivity is given in unit's ohm-meter (Ωm) (Gaffney and Gater, 2003; Reynolds, 2011).

There are three main systems by which a current can be conducted through a material. The first is electrolytic conduction which is the movement of ions through an electrolyte. The second is electronic conduction, which is the movement of electrons through a metal. The third is dielectric conduction, which occurs in materials that are very weak conductors when an alternating current is applied causing a shift in the electrons with respect to their nuclei (Reynolds, 2011 290). In the case of archaeology which looks mostly at soil and features within it, the current is being moved through the ions which are formed in the ground moisture (Clark, 1990).

With ground contact surveys being discussed an understanding is needed of how the current is passed through the Earth. When a single electrode is placed in homogenous material an applied current will flow radially forming a hemi-sphere. Within this hemi-sphere a potential gradient ($\frac{-\delta V}{\delta \chi}$) can be calculated which is the voltage drop between two points on the surface. This would be negative as the potential decreases in the direction of the flow of the current. A current density (j) can also be calculated which is the current divided by the area over which it is distributed ($\frac{I}{J} 2\pi r^2$). This information can then be used to calculate the potential difference (δV) of a hemispherical shell of thickness δr

$$\frac{\delta V}{\delta r} = -\rho \bullet J = -\rho \frac{I}{2\pi^2 r \bullet} \bullet$$

This equation can then be used to calculate the voltage Vr any distance (r) from the electrode.

$$V_r = \int \delta V = -\int \rho \bullet \frac{I \delta r}{2\pi r^2} = \frac{\rho I}{2\pi} \bullet \frac{1}{r} \bullet$$

This set of equations only deals with a single electrode which is not the case in archaeological investigation. If a second electrode is added, one being the source of the current and the other being the sink, where it leaves, then the potential distribution will change. The potential at any point is then the sum of the voltages from the two electrodes. The potentials at the two electrodes (E and G) would therefore be as follows with the two current electrodes being $B = +I$, $L = -I$. A visualisation of the following equations with matching electrode setup can be seen in figure 3.3

$$V_E = \frac{\rho I}{2\pi}[\frac{1}{BE} - \frac{1}{EL}], V_G = \frac{\pi I}{2\pi}[\frac{1}{BG} - \frac{1}{GL}]$$

From these equations, the potential difference can be calculated:

$$\rho V_{EG} = V_E - V_G = \frac{\rho I}{2\pi}[\frac{1}{BE} - \frac{1}{EL}] - [\frac{1}{BG} - \frac{1}{GL}]$$

This equation can then be rearranged to allow for the resistivity to be calculated:

$$\rho = \frac{2\pi V_{EG}}{I}[\frac{1}{BE} - \frac{1}{EL}] - [\frac{1}{BG} - \frac{1}{GL}]^{-1}$$

This helps us to understand how the basic functions of how current travels through the Earth and how this can be measured around a single or between two electrodes. However, this is theoretical in perfect conditions with a material that is homogeneous. In reality the Earth is not homogeneous which means that the resistivity measured in the field will be the apparent resistivity (ρa).

$\rho_a = RK$ where $R = \delta V/I$ and K (geometric factor) = $2\pi[\frac{1}{BE} - \frac{1}{EL} - \frac{1}{BG} + \frac{1}{GL}]^{-1}$

There are around 102 different electrode arrays that can be used to calculate the apparent resistivity (Reynolds, 2011 p294), however, only three, or a slight variety of, are generally used. These are Wenner, Schumberger and the dipole-dipole configurations. The type of configuration used often comes down to the preferences of the user, what they are familiar with, what processing ability they have and site logistics.

Depending on the configuration used the value of the apparent resistivity would change due to the geonomic function being influenced by the geometry. This can be seen in the following equations and visualised in Fig3.4:

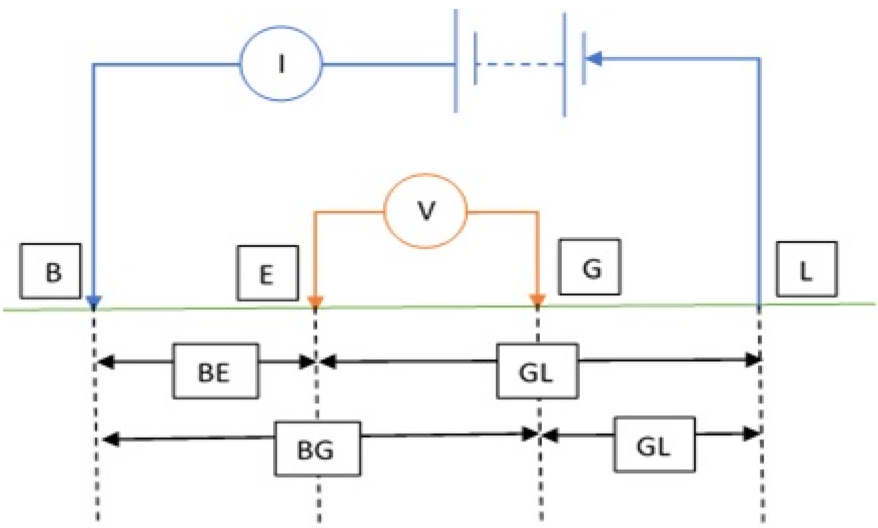


FIGURE 3.3: Four Electrode Resistivity Array: E and G represent Potential Electrodes and B and L represent Current Electrodes

Wenner: $\rho_a = 2\pi aR$

Schlumberger: $\rho_a = \frac{2\pi^2}{b}[1 - \frac{b^2}{4a^2}]R$; $a \geq 5b$

Dipole-dipole: $\rho_a = \pi n(n+1)(n+2)aR$

A proof of the Wenner can be seen if the distance between all the electrodes is equal (a):

If $\rho_a = KR$ and $K = 2\pi[\frac{1}{a} - \frac{1}{2a} - \frac{1}{2a} + \frac{1}{a}]^{-1} = 2\pi[\frac{2}{a} - \frac{2}{2a}]^{-1} = 2\pi a$

Therefore, $\rho_a = 2\pi aR$

It depends then upon the machine set up and interpretational computer programs as to which configuration would be used. There can also be more practical issues that dictate which configuration is used. For example, Schlumberger would not be suitable for CST but is very good for VES.

Resistivity techniques are adept at detecting different archaeological features that show a contrast in resistivity. This includes high resistivity features such

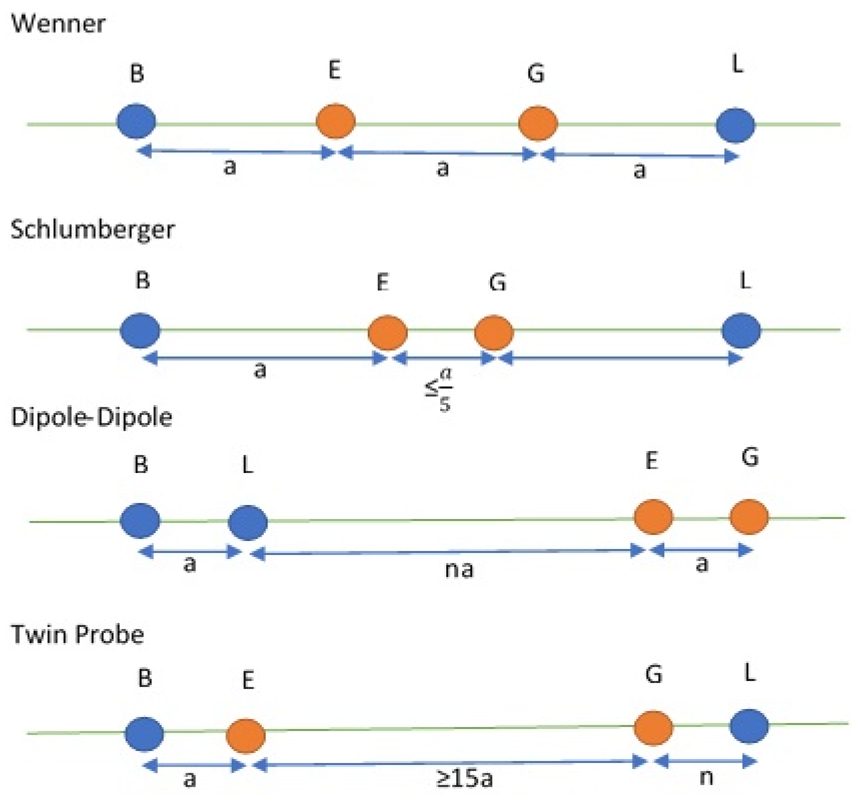


FIGURE 3.4: Electrode Layout for Resistivity Systems. Orange Dots Represent Potential Electrodes. Blue Dots Represent Current Electrodes

as walls, stone/tile work, or large deposits of material such as slag, as well as low resistivity features such as ditches and pits, or grave cuts.

With an understanding of how the technique works, its types and configurations, it can be seen that the most appropriate system for this project is Earth Resistivity Tomography in order to investigate the depth and form of features such as the technological waste deposit. Although this form of the technique is rarely used in archaeology, resistivity surveys are, and the data well understood. Therefore the data gathered in the earth resistivity tomography surveys should be comparable and interpreted in the same way. The type of features that may be present on iron production sites such as waste deposits, ditches and possible buildings are all the types of features that should be detected with resistivity techniques. As this technique records a 2D slice vertically down through the ground it allows for an understanding of the depth of deposits and anomalies.

(A) FlashRes 64 unit

(B) FlashRes 64 electrode line

FIGURE 3.5: FlashRes 64 set-up

The machine being used in the surveys for this project is the FlashRes 64 (Fig3.5a, the 64 denoting the number of electrodes utilised (Fig3.5b, with a power of 350V. Such a high voltage as used to attain around 0.006amps to make sure reliable readings are taken from appropriate depths. With this machine 64 electrodes are placed in the ground in a straight line with a set spacing between the electrodes, for example 0.5m or 1m which will give an effective depth of investigation of half the distance between source and sink electrodes.

Data collected from this survey will be post-processed in the computer programme Surfer to produce a heatmap of the data. An example of this can be found in appendix A.2.2.

3.2.3 Induced Polarisation

The history of this technique follows a similar line to many others. It started in the early 20th century with advancements in the 1940s due to its use by the military in WW2 to locate mines. After the war the technique was picked up by the petroleum industry and from the 1970s on-wards, access to computers and increasing analytical power, the technique continued to develop. The main use of this technique currently is in the exploration and detection of disseminated ores in the mining industry (Saad et al., 2013). This technique is very rarely used in the field of archaeology, therefore the discussion throughout this chapter will be mainly based on its use and application in the field of geology.

Induced polarisation measurements are taken with the same electrode configuration as for resistivity and certain systems are able to take both measurements in the same survey. In resistivity, as we have seen, a current is applied between two electrodes. When this current is switched off the voltage between the potential electrodes does not instantly return to zero but decays slowly due to the materials within the ground becoming polarised and acting like a capacitor, holding the charge temporarily. This occurs in reverse when the current is reapplied. The voltage does not peak instantly but gradually increases over the same time it takes to decay or *vice versa*. This data can be recorded in four different ways; time domain, frequency domain, phase domain, and spectral Induced Polarisation (Everet, 2013).

If a current is applied to an area where material is present that allows induced polarisation an observed voltage will be seen which consists of the true voltage which is instantaneous plus a polarisation voltage (overvoltage) which increases gradually over time until the observed voltage is reached. When the current is then switch off it will decrease instantaneously by the actual voltage leaving the overvoltage which will decay over time to zero (fig.3.6). The ratio of overvoltage/observed voltage is used to calculate the chargeability. This decay can then be measured by calculating the area under the curve of overvoltage decay which is completed by the instrument by measuring the voltage. This is done at a set time after the actual voltage is turned off and then at a number of discreet time intervals after the initial measurement. This data is then integrated with respect to time and divided by the observed voltage to give an apparent chargeability. A true chargeability is near impossible to calculate in non-laboratory settings as the different layers and material in the ground will have their own values of chargeability

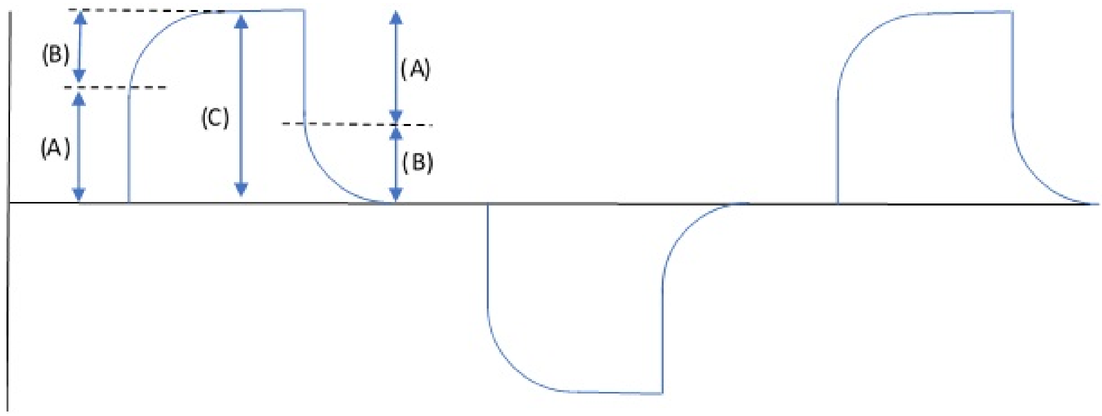


FIGURE 3.6: Charge overvoltage of an alternating current causing induced polarisation: (A) Initial Voltage, (B) Overvoltage, (C) Observed Voltage

When two metal electrodes are placed in an ionic solution and a voltage passed between them the balance in ions is disturbed causing a current to flow which causes a potential difference between the electrodes. In a geological setting the ionic solution tends to be the moisture of groundwater. These fractures or pores form channels for the current to pass through. On occasions these channels can become blocked with grains which could be electronically conducting. If this is so a charge will build up at the grain causing it to become polarised creating another potential difference across the grain. Once the voltage is removed the ions will diffuse back into solution causing the potential difference to reduce to zero across time. This is the overvoltage seen and recorded in time-domain techniques. This grain polarisation is a surface phenomenon. This is important when talking about disseminated ores. Although the disseminated ore is formed of lots of individual mineral grains they take on a net response which is measured in the Induced Polarisation response. This could be important when it comes to iron production sites which might have ore disseminated throughout the waste deposits. Another cause of polarisation in membrane polarisation. This occurs in two ways. The first is if there is a narrowing of the channel the current is passing through then there will be a build-up of charge opposite to what the channel is made of. Therefore, if the channel was formed of a negatively charged material then there would be a build-up of positively charges ions causing a block and hence a potential difference. As before when the voltage is removed the ions will return to solution and the decomposition measured giving an Induced Polarisation. The second is the inclusion of clay particles in the channel. These don't always block the channel but tend to be negatively charged. When a voltage is then applied positively charged ions will attract to these negative particles forming concentrations which allow the movement of positive ions but trap negative ions. Once the voltage is removed these ions then diffuse back giving an Induced Polarisation measurement.

Induced polarisation surveys are used very rarely in archaeological investigation. As has been seen, the data collection happens simultaneously with Earth Resistivity Tomography surveys. Therefore, Induced Polarisation was chosen in this instance to test its application on an iron production site, and its potential for identifying archaeological deposits. With its use in geology to identify disseminated ores, it is believed this will be able to identify technological waste deposits due to iron ore often being a constituent part. It added no more time or energy expenditure to gain another data-set, except in post processing and interpretation of the data. Moreover, as the data is collected at the same time as Earth Resistivity Tomography it also collects data in a 2D vertical slice through the ground, giving potential information on the depth and form of deposits. The survey was carried out using a ZZ FlashRes 64 (Fig3.5a). The two configurations used in this survey were a 1m electrode spacing giving a 64m survey line and a 0.5m electrode spacing giving a 32m survey.

Data collected from this survey will be post-processed in the computer programme Surfer to produce a heatmap of the data. An example of this can be seen in appendix A.2.3.

3.2.4 Electromagnetic

Electromagnetic survey methods were developed post World War 1 for the exploration and detection of hydrocarbons in the oil industry. This technique was then developed over the following decades for hydrocarbon and mineral exploration and many forms of environmental applications (Reynolds, 2011 403). Electromagnetic surveys did not enter the commercial sector until the latter decades of the 20^{th} century, and even to this day its use in archaeology is not widespread or commonplace.

Electromagnetic surveys cover a number of different methods with many different instrumental systems covering an even larger array of applications. At their core, electromagnetic systems are either time-domain or frequency-domain. The former measurements are taken as a function of time and the latter at a single or multiple frequency. Within these two domains the techniques can either be active or passive. Active techniques being where an artificial transmitter is used to create a field, and passive techniques where the natural field is used (Reynolds, 2011 404). In this project a frequency domain active system was used, and will be the one discussed.

Due to the fact that electromagnetic radiation/waves are used in this survey the results can be split into a function of either magnetic response, in-phase, or electrical response, quadrature. Both EM systems create a primary electromagnetic field via a transmitter that is formed of a coil of wire through which an alternating current is passed. This primary electromagnetic field then interacts with magnetic or conductive features within the Earth and the resulting change detected.

When the primary electromagnetic field passes over a magnetic anomaly this primary field is altered in amplitude and it is this interference and change that is detected. This is known as in-phase which is measured in either parts per million (ppm) or the dimensionless unit SI. This can also be seen as the detection of magnetic susceptibility which is more commonly used in the field of archaeology. When the primary electromagnetic field passes over a conductive anomaly it causes electrical eddy currents within the anomaly. In turn these eddy currents cause the creation of a secondary electromagnetic field. The secondary electromagnetic field is then detected by the same receiver that is detecting the primary magnetic field. The secondary electromagnetic field is directly related to the conductivity of the anomaly, which can be calculated by the machinery being used. This is known as out of phase, or more commonly, quadrature and is measured in parts per million (ppm). The conductivity can be viewed as such, or perhaps more helpful in archaeology is that it is the inverse of resistivity.

Both these functions can be more easily visualised by sinusoidal waves. The primary electromagnetic field and and in-phase response can be viewed as a cosine wave that is at peak amplitude at time 0. The secondary field can be visualised as being a sine wave which reaches peak amplitude at 90^o or $\frac{\pi}{2}$ after the cosine wave. These two sets of information can then be separated mathematically to produce the two data-sets.

In frequency domain systems a number of different frequencies can be used to obtain data. The higher the frequency the nearer to the ground surface the data will be collected from as the higher frequency attenuates faster than lower frequencies which will penetrate deeper into the ground surface. All data collected is done so as an average of the ground volume from the point of the coil. Therefore if a high and low frequency survey were to be carried out over the same area the low frequency survey would include the ground volume covered by the high frequency survey.

EM surveys are infrequently used in archaeological investigation. The first reason for choosing EM is to test its viability for the investigation for iron production sites. As has been seen the EM technique gives a number of data-sets simultaneously including the detection of changes in magnetic susceptibility and conductivity at a variety of assumed depths. The magnetic and conductive responses of features such as ditches, pits, and walls are well studied and known in archaeology due to magnetic susceptibilty machines being available as standalone survey devices and the conductive response being the opposite of resistivity responses. Many of these features could exist on iron production sites, but most importantly this technique could be used to help identify the extent of the technological waste deposit as this is believed to have increased magnetism and decreased conductivity. Therefore, this technique allows for the investigation of a variety of anomalies at different depths, looking at their magnetic and conductive response, along with being directly comparable to both the magnetometer survey and Earth Resistivity Tomography survey.

The surveys were carried out using a GSSI EMP-400 (Fig3.7) with a frequency of both 3kHz and 15kHz collecting in-phase and quadrature data. Data collected from this survey will be post-processed in the computer programme Surfer to produce a heatmap of the data. An example of this can be seen in appendix A.2.4.

(A) GSSI EMP-400

(B) Electromagnetic survey in progress

FIGURE 3.7: Electromagnetic equipment and use in field

3.3 Excavation

Once geo-prospection surveys are completed, targeted excavations can occur on the site to investigate interpreted features more efficiently, and the surveys themselves can be ground-truthed. The aim of excavation in this project was to investigate the technological waste deposit, collecting material to create a dataset of the quantification and characterisation, as well as a typological classification.

It was decided that spit excavation rather than context excavation was the best approach for this project for a number of reasons. The first is that the excavations into the waste deposits was designed to collect samples in a quantitative way. By excavating in spits this could be achieved by keeping a standard volume. Moreover, the practicalities of excavating into a waste deposits is easier in spits as contexts can be difficult to detect when excavating, but much clearer when seen in section. By excavating in spits, it allowed for rigorous collection of material that could be linked back to contexts during the analysis phase, gaining information in both respects. For this project it was decided that 0.1m spit depths would be appropriate to start and could be increased if the size of samples increased and spanned more than one spit. It is believed this spit depth will give a high definition of the deposits when the material collected is analysed. This type of excavation has been used effectively in a number of projects investigating waste deposits including Sri Lanka (Juleff, 1998) and Sudan (Humphris and Carey, 2016).

For the large-scale sorting of material on site by size a sieve was deemed to be the best method. Archaeological sieves were deemed too expensive for this project and too small to hold enough volume of material to make the process efficient. It was decided the best way to attain the perfect sieve for use was to build one specifically for the project. The sieve was built by purchasing two plastic storage boxes one large, to act as a way to catch all material that drops through the sieve, and one smaller that sits just inside the large but not all the way supporting itself on its rim so that it can be moved back and forward like tracks. The centre of the base was cut out of the small box leaving a ledge. A wooden frame was then made to fit in the base and a mesh of appropriate size fitted over the wooden frame. A number of wooden frames were made of different size mesh. These could then be interchanged in the sieve meaning the same equipment could be used to separate the material to different sizes.

A specific outline of excavation processes for each case study is given in their individual appendices as there was slight changes in the processes between the two excavations. All trenches were positioned in areas that were believed to represent the true technological waste deposit, as interpreted from geo-prospection surveys, along the line of the ERT/IP survey line.

A set excavation strategy was formed to be used across both case study sites to standardise the practice and the collection of material the analysis phase. This strategy will be set out here. However, slight amendments were made between the two case studies as a greater understanding of the process was gained in the field. This involved adding a second sieve size for use at Standen, with all material being passed through the new sieve size off site. This will be discussed in more depth in the individual case study chapters, 5 (section 5.2) and 7 (section 7.2).

- 1 - Remove topsoil down to archaeological deposit
- 2 - Set string around the bottom edge of the trench to delineate the top of the first spit.
- 3 - Photograph and prepare paperwork and bags for material collection for spit.
- 4 - Excavate spit to a depth of 0.1m with reference to delineating string.
- 5 - Weigh total material and record.
- 6 - Sieve all material recording weights and amount collected
- 7 - Repeat steps 2-6 until the natural geology is reached.
- 8 - Plan and record trench sections
- 9 - Once all paperwork complete back-fill trench.

When the topsoil is removed during excavation of the trench, care should be taken as later processes such as ploughing could have mixed and moved material, such as pottery. Although this material is not in a sealed context it still adds a level of information to the site in general, and could be an example of dating evidence which is rare in technological waste deposits. These artefacts should therefore be sampled and recorded as topsoil finds. Moreover, processes such as ploughing can make the division with the true archaeological context unclear. It is therefore better to err on the side of caution and start the spit excavation when it is believed the sealed archaeological contexts have been reached. If this is not the case the data can be ignored, however, if caution is not taken data could be lost. If the top of the archaeological context is not flat then this can be levelled for ease of excavating all future spits. The material removed through levelling should be recorded and material collected as though it was a normal spit but a note made this is an incomplete spit for the sake of levelling.

For this project sieve sizes of 25mm and 6mm were used. This created the size categories of materials mixed large, mixed small and mixed matrix as set out in figure 3.8. All material was washed with a 50μ mesh being used for the washing of the mixed matrix. This created a large category (>25mm), small (<25mm>6mm), matrix (<6mm>50μ), and fine residue (<50μ). The entirety of the Large category was removed from the site, 25% by weight of the Small and 10% by weight of Matrix. All material removed from the trench should be weighed and recorded. This gives the total weight of the trench for the calculation of % weight of the datasets to be discussed. Each size category should also be weighed in its entirety also allowing for the calculations of % weight. Data can also be extrapolated. An example of this is the 25% by weight of material collected for analysis of the Small category can be multiplied up to infer on the entire spit.

3.4 Analysis of datasets

Throughout the fieldwork in this project a number of datasets were collected for analysis through geo-prospection and excavation. The types of datasets will be discussed in this section along with how they are analysed and what information should be gained from this.

The geo-prospection surveys will create seven datasets, as discussed earlier in this chapter. These include one each from magnetometry, earth resistivity tomography, and induced polarisation, and four from the electromagnetic survey, including in-phase and quadrature both at 15kHz and 3kHz. Each of these datasets can be analysed within themselves comparing readings and anomalies/structures to understand how features are formed across the site. They can also be compared giving an understanding of the structure and composition of features according to their magnetic and electrical responses. These can then be used to more accurately position trenches for excavation as well as comparing to these results to ground-truth the survey data.

The material collected from the excavation will create three datasets. These

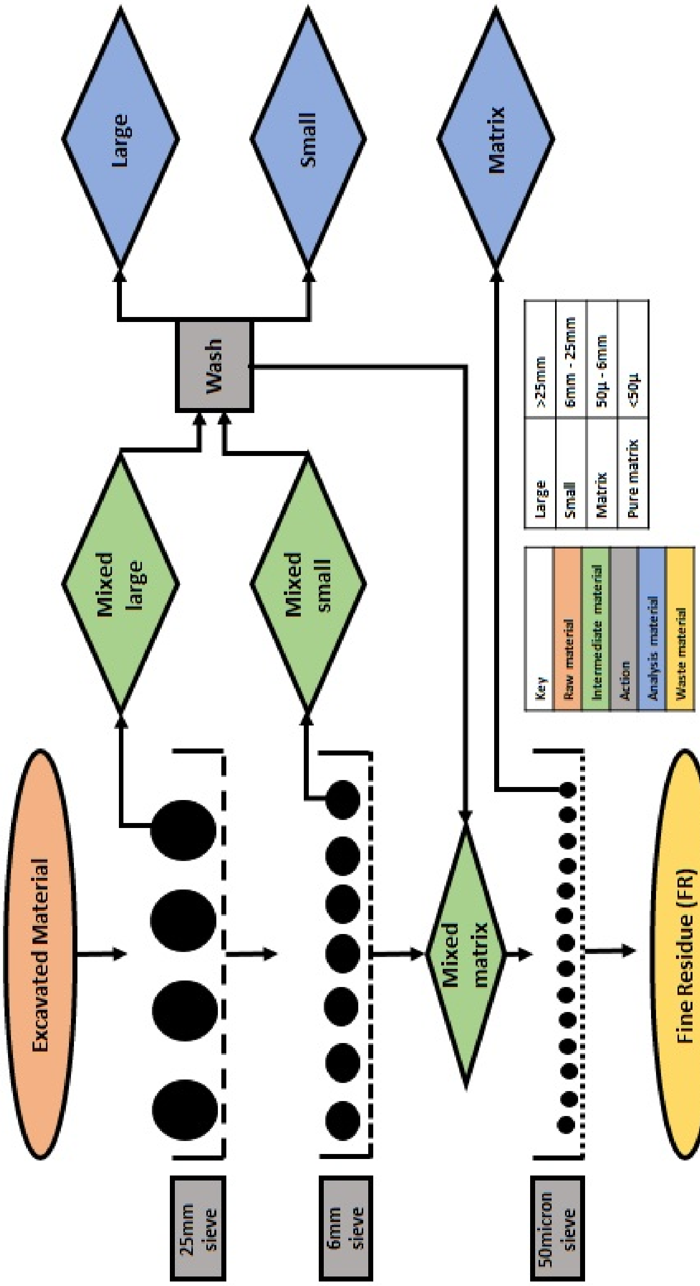


FIGURE 3.8: Material separation schematic with size categories and material output

include quantification and characterisation of the waste deposit, and a typological classification. From the quantification dataset the volume of the deposit can be calculated, due to the known volume of the spits 1mx1mx0.1m, as well as the volume of material that forms this, for example technological waste and matrix. The volume of materials can be difficult and time consuming to calculate with potential margins of error, therefore the quantification datasets will be produced through percentage weights of materials. This will create a more comparable dataset, even between spits of different volume. From this dataset an understanding can be gained as to the constituent volume by percentage weight of the technological waste deposit. The typological classification will create a dataset in which all the material collected will be grouped into a type defined by material type, eg slag, furnace material or geological, with further sub-types being defined by physical form and characteristic, such as surface texture, fracture, and porosity. From this dataset an understanding of the technological processes occurring on the site can be understood, and will be discussed further in the next section. The characterisation dataset will be formed of data from both the quantification and typological classification, which will create an understanding of change in the character of deposition through the profile of the waste deposit. The % weight of materials or types can be compared across spits through the deposit to show how these might or might not change and fluctuate, showing trends that could inform on change of technology and the smelting process.

Once material has been removed from the site to an appropriate area for analysis it first has to be washed. This is time consuming process, but highly necessary for further analysis. Due to the thickness and stickiness of Wealden clays, the Large category could not be cleaned by hosing or agitation in water as there is a variety of surface textures and porosities in which the clay becomes stuck. It therefore need to be scrubbed individually with a brush in water. Great care must be be taken in cleaning samples as there are many fine features and textures on the samples which could be obscured and missed which in turn would have influenced the typological classification. The water has to be frequently changed for fresh water as the clay becomes a suspension and the washing process becomes less effective and efficient. Small and Matrix samples could be washed under flowing water in bags made of 50micron mosquito netting. Using mosquito netting was cheaper than purpose-made membrane and can be cut into whatever size necessary to hold samples. Agitation of material within the bag under the flowing water seemed to be adequate enough to remove the clay and pure matrix. This could be due to the Small and Matrix size categories have less larger surface features and porosities for the clay to become trapped in. As all material was also weighed to understand percentage weights the more matrix left on the samples the less accurate these percentage weights will become.

3.4.1 Classification of technological waste

To form the typological classification dataset, which will also feed into the deposit characterisation dataset, the material needs to go through a macro-visual analysis. An attempt was made to take a non-bias approach to the classification of the technical smelting waste samples by not creating a pre-defined classification scheme to fit the material to but rather forming one as the analysis progressed. Using this approach, rather than pre-defined, stops border-line samples, which could fit into a number of categories or not quite into any, being placed in a category as a nearest fit. In such a case a new category could be created. It is believed this will create a more rigorous classification of the technological waste, drawing out finer detail of the variety of forms of technological waste produced in a site.

Even though a non-biased approach was taken an understanding was gained of technical smelting waste before-hand, by looking at other physical data-sets from Exmoor and Sudan, as well as literature sources for identification including the standards set by Natural England for the identification of metallurgical debris. This knowledge and experience of handling and identifying technological smelting waste is important as it forms an understanding of the material. This should lead to less human error in the classification, giving a clearer understanding of the forms and features that may occur in the material.

Only the large material collected during excavations was used for classification. The first reason for this that the larger material contains more features with which to create the classification scheme, which was not possible in a lot of cases with the material from the Small and Matrix categories. Secondly the time constraints on the project meant as much information has to be gained in the shortest amount of time, and the Large category did this most efficiently. The only classification that was undertaken on the Small and Matrix categories was to separate into material types; slag, furnace material, and geological.

The way in which the process of classification was approached was as such. All clean large material from a single spit was emptied into a pile. This was then sorted into sub-piles of samples with similar characteristics. This began with the basic splitting by material type, slag, furnace material, and geological, and then by shared traits, primarily surface textures. These sub-piles then became the types in the spit, being named after the predominant surface trait. Once all the material was separated into types a more in-depth classification was completed on each type with the details recorded included site, trench number, spit number, material, type, number of samples, combined weight of samples, minimum size, maximum size, shape, fractured sides, porosity shape, porosity size, porosity percentage, vitrification, impressions, inclusions, viscosity, magnetism, and a discussion section on distinguishing features. Once this was completed all data was input into a digital format, so it could be investigated statistically.

4 Case Study 1 : Chitcombe - Part A - Geo-prospection

4.1 Introduction

Case study 1, Chitcombe, involved three major stages of investigation. Geo-prospection investigation of the site, excavation and analysis of material, creating a number of large and complex datasets. Due to this the Case study has been divided into two Chapters. This Chapter, Part A, will focus on the background to the site, and present the geo-prospection surveys that were undertaken on the site. This will include the field strategies used, primary data collected, and a discussion of the data, with all supporting datasets being set out in Appendix A. These will be cross referenced throughout. The following Chapter, Part B, will focus on the Excavations and Deposit sampling, again looking at the strategies used, primary data collected and a discussion of that data, with all supporting datasets being set out in Appendix B, and cross referenced throughout.

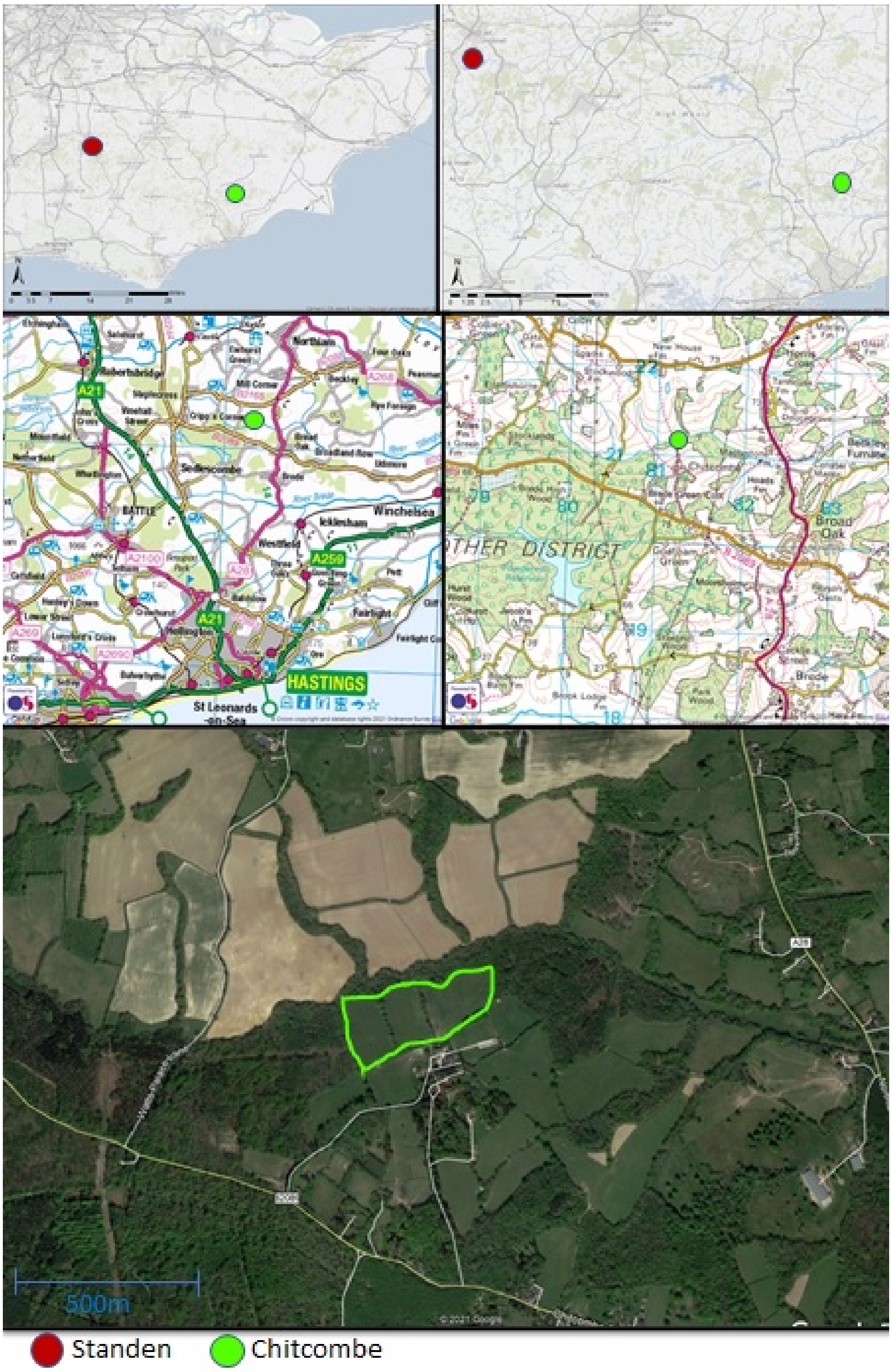


FIGURE 4.1: Position map of Chitcombe

4.1.1 Location

The Roman iron production site of Chitcombe, national grid reference TQ 813 211, is positioned approximately 300m north of Chitcombe road (B2089) between Cripps Corner and Broad Oak, overlooking the Tillingham valley (Fig. 4.3) and on the lands of Chitcombe Farm.

4.1.2 Previous Investigation

The earliest reference we have to the Roman iron production site at Chitcombe (Fig. 4.2), Broad Oak, East Sussex is by Rock (1879). Rock had visited the land previously to see the gardens and had noticed tiles which he was told were from the local area. Believing these to be of Roman origin he planned to return for more thorough investigation (Rock, 1879 176). Upon approaching the site Rock (1879) recorded, 'the remarkably hard surface of the private road, and, on examining it, we found that it is made of extremely hard fragments of scoriae, almost like iron itself. This road…has been made nearly twenty years, and had needed no repairs'. This road is still in use today and iron slag is still evident. Rock also recorded a number of pits when examining the woodland both around the site and in the surrounding local woodland, which he attributed to removal of iron ore for the production of iron. Once down in the ghyll, Rock (1879) describes how the slope of the hill to the south 'appears to form a series of swelling head-lands, with smooth intervening valleys…seen from below, the headlands jut out, and form small cliffs, at the height of about fifty feet above the bed of the stream'. Upon investigation, Rock (1879) discovered that the headlands were waste deposits from iron production and the

FIGURE 4.2: View over Chitcombe
Top - View from the ridgeway down across the site
Bottom - Birds-eye view of area of investigation

intervening valleys had little waste. Rock (1879) came to the conclusion that there must have been two different processes occurring on the site with 'the tips of waste, probably the result of smelting the ore in furnaces, and there is also the mound system, which appears to have the same stratification as that at Beauport.'. There was very little to no understanding of the bloomery smelting process at this point so the conclusion of two different processes may be wrong. However, it could show a variation in tipping and discard practices.

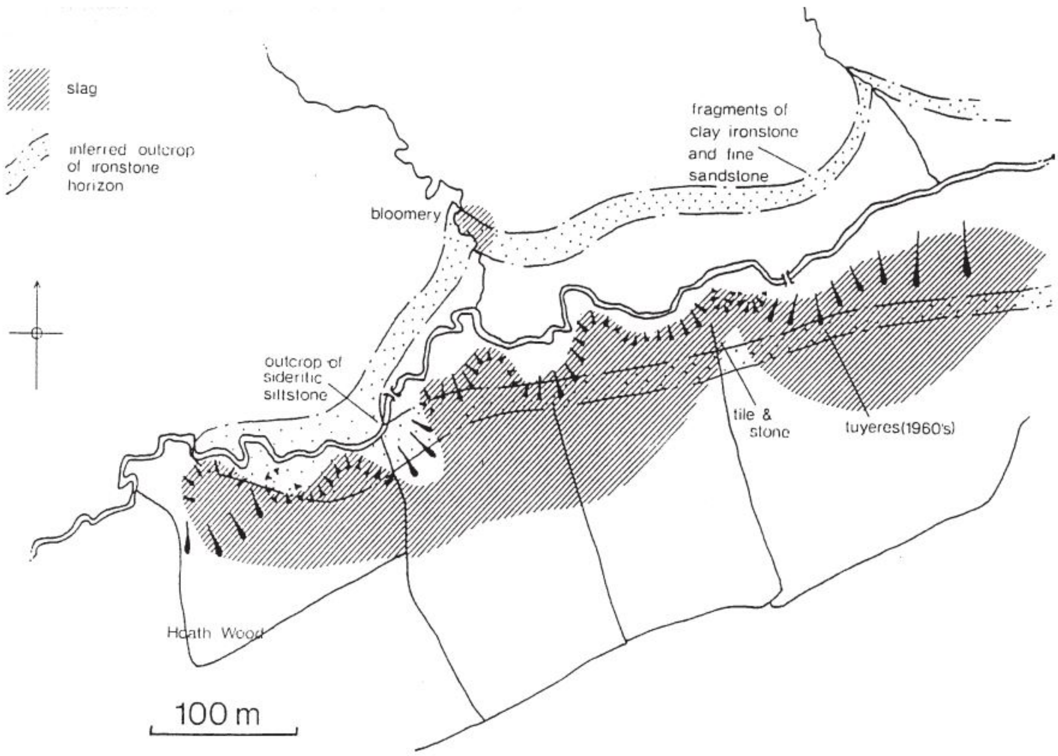
During his time at Chitcombe, Rock (1879) 'dug several holes' varying in depth between one to five feet (0.3-1.5m). He noted that the top soil varied depending on where on the slope he was digging but at its greatest depth was four to five feet (1.2-1.5m) due to hillwash. Although he did not record where he dug he did record the type of artefacts he discovered. These included 'fragments of coarse pottery, pieces of well-made brick, two inches thick, tile about one and a quarter inch thick, and occasionally fragments of bright red tiles, nearly an inch thick, some marked with a pattern of a number of small wavy lines, and others with radial lines', which Rock (1879) stated were so common it 'mattered little where we dug' these noted artefacts were discovered. Moreover, under a well established bank and hedge a wall foundation was discovered, constructed of stone and mortar, and was followed for a length of five or six feet (1.5-1.8m). Rock (1879) also dug 'half way up the hill' where it was said the 'plough could only enter a small depth'. Here he discovered a hard surface of slag which was identified as the surface of a trackway.

In January and February 1987, WIRG visited Chitcombe to examine the site and update information with more modern understanding and technology. A metal detector and home-made magnetometer were used to identify the extent of the slag which was shown to extend for around 600m along the lower edge of the valley along the river edge (Hodgkinson, 1988 2). Along with identifying the extent of the slag, a number of different types of slag were identified including 'large flat cakes of tap slag, furnace bottoms, cinders from within the furnace' as well as 'burnt clay and furnace lining' (Hodgkinson, 1988 2).

FIGURE 4.3: Slag in the river Tillingham along the north side of Chitcombe

During this foray the hedgerow noted by Rock was identified with stone and striated tile exposed on the surface. Tile was also discovered in the stream nearby. These included box flue, with various combing patterns, along with tegula and imbrx. These were examined by Dr David Rudling who confirmed they were Roman (Hodgkinson, 1988 2-4).

The WIRG field group were shown an area where slag had been taken in the 1960s for agricultural purposes, where, at the time, a stone base was discovered



Chitcombe Romano-British Ironworks, Brede

FIGURE 4.4: Inferred extent of slag at Chitcombe (Hodgkinson 1998, 2)

and a number of tuyere's were discovered, one an intact double tuyere. As well as this, on the north side of the valley opposite Chitcombe a small deposit of slag was discovered on a small tributary (Hodgkinson, 1988 4).

In 2001 the Hastings Area Archaeological Research Group (HAARG) visited the site to examine the landscape and look for further surface finds. This led to the discovery of more box flue fragments, pottery, burnt clay, slag and two pieces of mortarium. This mortarium has been dated, on the basis of form, to between AD 50 and 80 (Cornwell and Cornwell, 2016a). HAARG returned a few years later and gained permission from the landowners to undertake more intense investigation on the site leading to a magnetometer survey of the site between 2013-2014 (fig.4.5). This culminated in the surveys and excavation set out in the rest of this chapter.

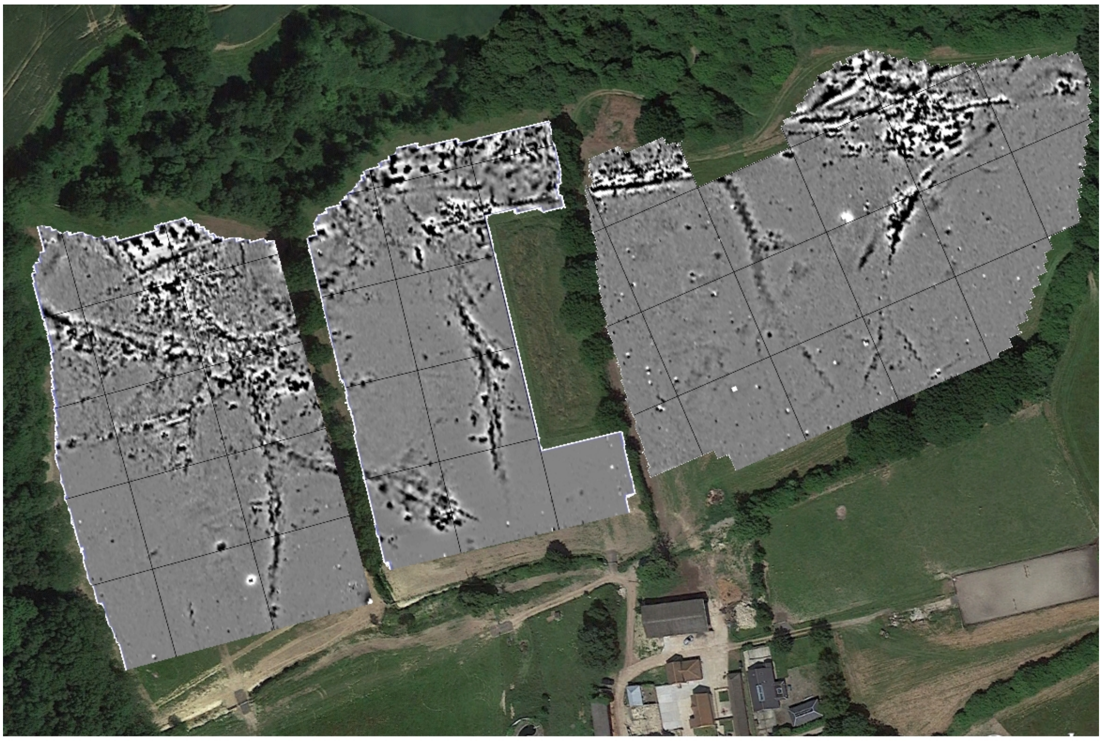


FIGURE 4.5: HAARG magnetometer survey

As with all Romano-British iron production sites in the Weald, Chitcombe should not be seen as a single entity but rather observed in the wider landscape. The site is situated just north of Margary (1965) 'track II' which runs in an east-west orientation from Rye to the area around Uckfield. This track is intersected by a number of other 'tracks' and 'routes'. One of these is 'route I' that runs in a north-south orientation from Rochester, where it meets Watling Street, to the Hastings area (Margary, 1965 208-209). Along 'route I' are positioned a number of major iron production sites. To the north of the junction this includes Bodium, which includes a Classis Britannica harbour, and the Classis Britannica iron production site of Little Farningham Farm, Cranbrook. To the south of the junction the route passes close by or through Footland Farm, Oaklands Park and Beauport Park, three of the largest iron production sites in the Weald (Cornwell and Cornwell, 2016a 7). Beauport Park, the largest known iron production site, has impressive remains of a Classis Britannica bathhouse. The intersection of 'track II' and 'route I' occurs around two miles to the west of Chitcombe offering relatively quick and easy access to major transport links joining other large production sites.

Chitcombe is not only connected to the wider landscape by roads but also by waterways. The site sits at the upper extent of the river Tillingham. Although not navigable at the point of the site it would only be a short walk of around a mile until the river would have been navigable for smaller craft. The river then continues its course in an easterly direction where it meets the river Rother at Rye. Around two miles south of Chitcombe is the river Brede, which has evidence of a Roman quay in its upper reaches in the village of Bodium (Lemmon and Hill, 1966), which is also positioned along Margery's 'route I'. The river Brede runs roughly parallel to the Tillingham until they both converge with the river Rother in the same area just outside of the town of Rye. Where these rivers join and exit into the English Channel today is a large area of reclaimed land. This means it is difficult to know the exact shoreline during the Roman period and how wide and far inland the estuary existed, therefore where these rivers were navigable to.

4.1.3 Aims and objectives

The aims set out here are the general aims for the case study and are therefore the same in Part A and B. The objectives will be different as they are specific to the datasets being covered.

Aims:

- Understand the organisation of the Roman iron production site at Chitcombe.
- Test methods for investigating iron production sites to calculate the horizontal and vertical extent of deposits with a focus on the technological waste deposit.
- Quantify and characterise technological waste to gain a true understanding of what forms the technological waste deposits and the development and changes that occurred in technological processes.

Objectives:

- Use a combination of geo-prospection techniques to investigate the spatial distribution of features across the site.
- Use a combination of geo-prospection techniques to investigate the spatial form of anomalies and features, namely the technological waste deposit.
- Use a combination of geo-prospection surveys to understand the different physical responses of features and anomalies.

Before any work took place on site, landowners were contacted and all appropriate permissions granted.

4.2 Field Strategies and Data Collection

Four types of geo-prospection surveys were used across the site (fig 4.6). This included magnetometry, earth resistivity tomography, induced polarisation, and electromagnetic surveys. How these survey types work, what anomalies they can detect, and the specific apparatus being used in this project is set out in chapter 3, section 3.2. Why and how these surveys were deployed in the field throughout this case study will be set out here. All raw data collected can be seen in Appendix A.1.

4.2.1 Magnetometry

As has been discussed in Chapter 3 magnetometry is widely used in archaeology and is highly applicable in detecting features that would be expected on iron production sites. HAARG conducted a magnetometer survey at Chitcombe using a Bartington Grad-601 twin probe taking 4 readings per meter. It was therefore decided this technique should be used in this project to collect a higher resolution raw dataset, which allows for a more in-depth analysis and application in mapping features which is one of the aims of this project.

The magnetometry survey was completed across the site in the spring of 2016

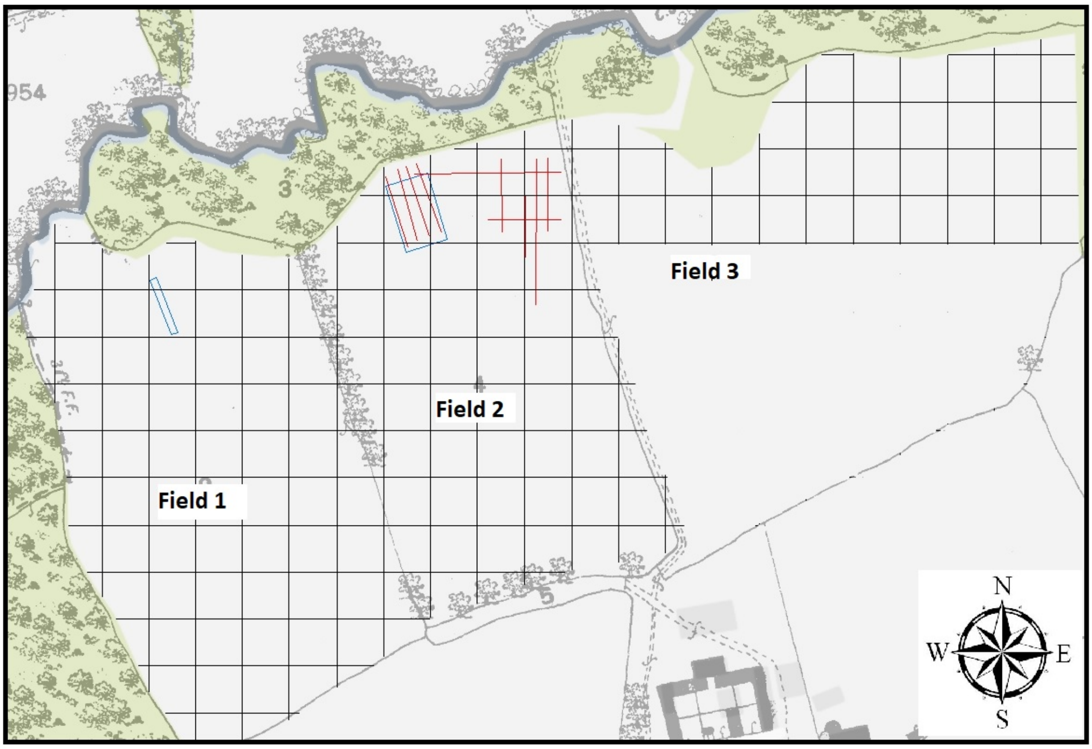


FIGURE 4.6: Geo-prospection survey grids. Black=Mag, Red=ERT/IP, Blue=EM

using a Bartington Grad 601 twin probe. The detection limit, the highest magnetism that is record, was set to 1000nT rather than the standard 100nT. Although this loses a small amount of definition between 0-1nT, it allows for a greater understanding of anomalies between 100-1000nT. Many features within this magnetic range would be expected on an iron production site. Grid sizes of 20mx20m were used as this was the most efficient size for a single person to set up and move while surveying in open field. Line transects were set to 1m with 8 readings being taken per meter along the transect, giving 1600 readings per grid, as this was believed to strike an efficient balance between time and energy surveying and data collected.

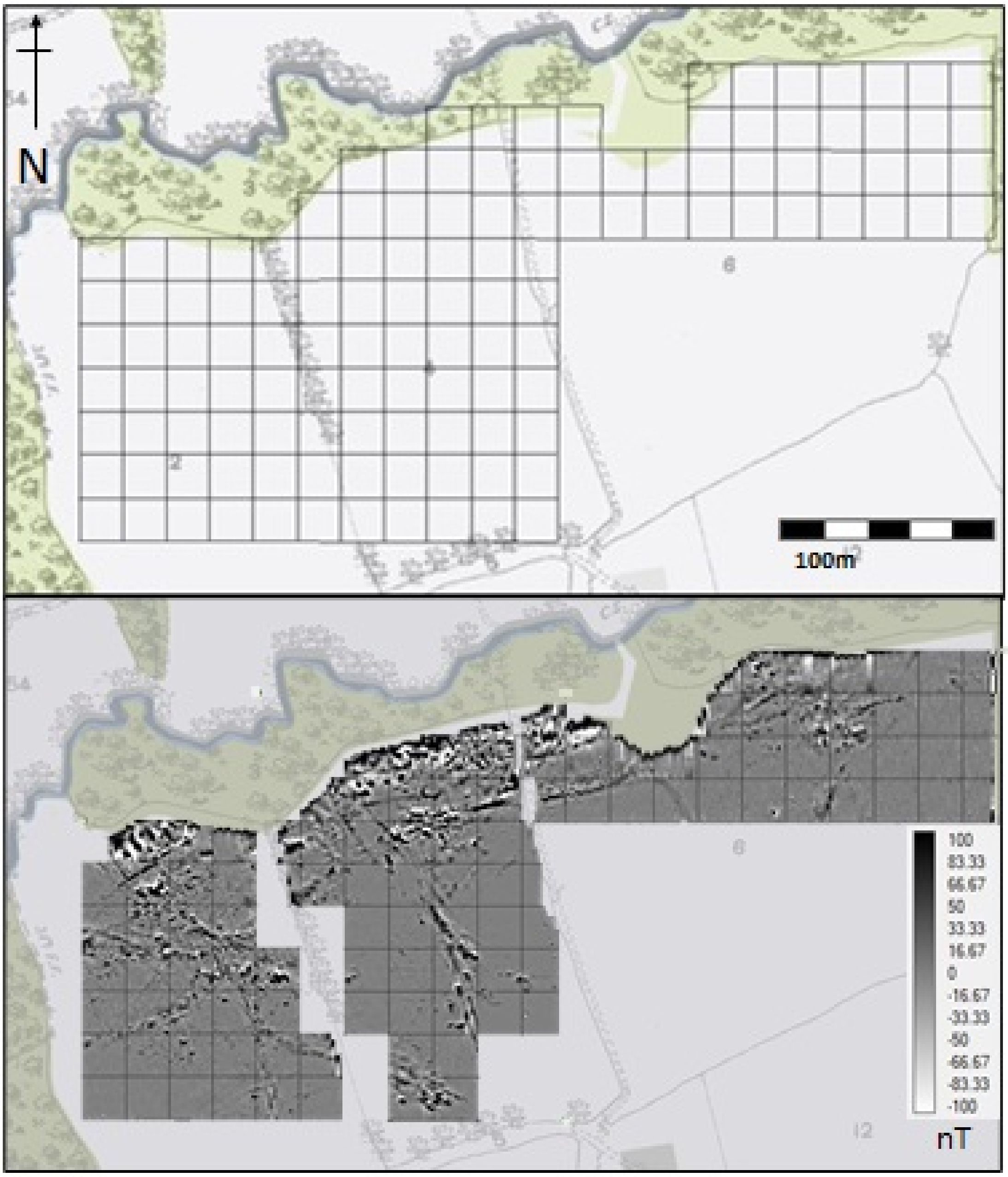


FIGURE 4.7: Plan of magnetometry survey grids (top), example data (bottom)

Three fields were surveyed using magnetometry with field 1 in the west and field 3 in the east. The raw survey data is set out in Appendix A.1.1. All fields were under grass for grazing horses. A total of 126 full or partial 20x20m grids were surveyed. Across all three fields a large number of magnetic anomalies were detected including a number of linear anomalies, highly magnetic discreet anomalies and area of mixed magnetic response (fig 4.7). The majority of anomalies detected in this survey are positioned along the northern edge of the survey with a full interpretation given in section 4.3.1.

4.2.2 Earth Resistivity Tomography

As seen in Chapter 3, resistivity surveys are common place in archaeology and their responses well understood. Earth resistivity tomography is applicable for this case study as it can detect a number of features expected at Chitcombe. The main reason for the use of this technique is due to it taking readings as a vertical section through the ground. This then allows for the investigation of the vertical extent of deposits, namely the technological waste deposit, which is one of the aims of this project.

The earth resistivity tomography surveys were completed across the site in two periods, the first in the summer of 2016, the second in the summer of 2017 (fig 4.8). These were completed using the ZZ FlasRes64, utilising two different electrode spacings, 1m and 0.5m. These give survey line lengths of 64m and 32m respectfully. The surveys completed in 2016 targeted the northeast of field 2, based on surveys and interpretations from Hodgkinson (1988), and Cornwell and Cornwell (2016a), which showed the technological waste heap to extend into this area. The 2017 surveys targeted the north of field 2, based

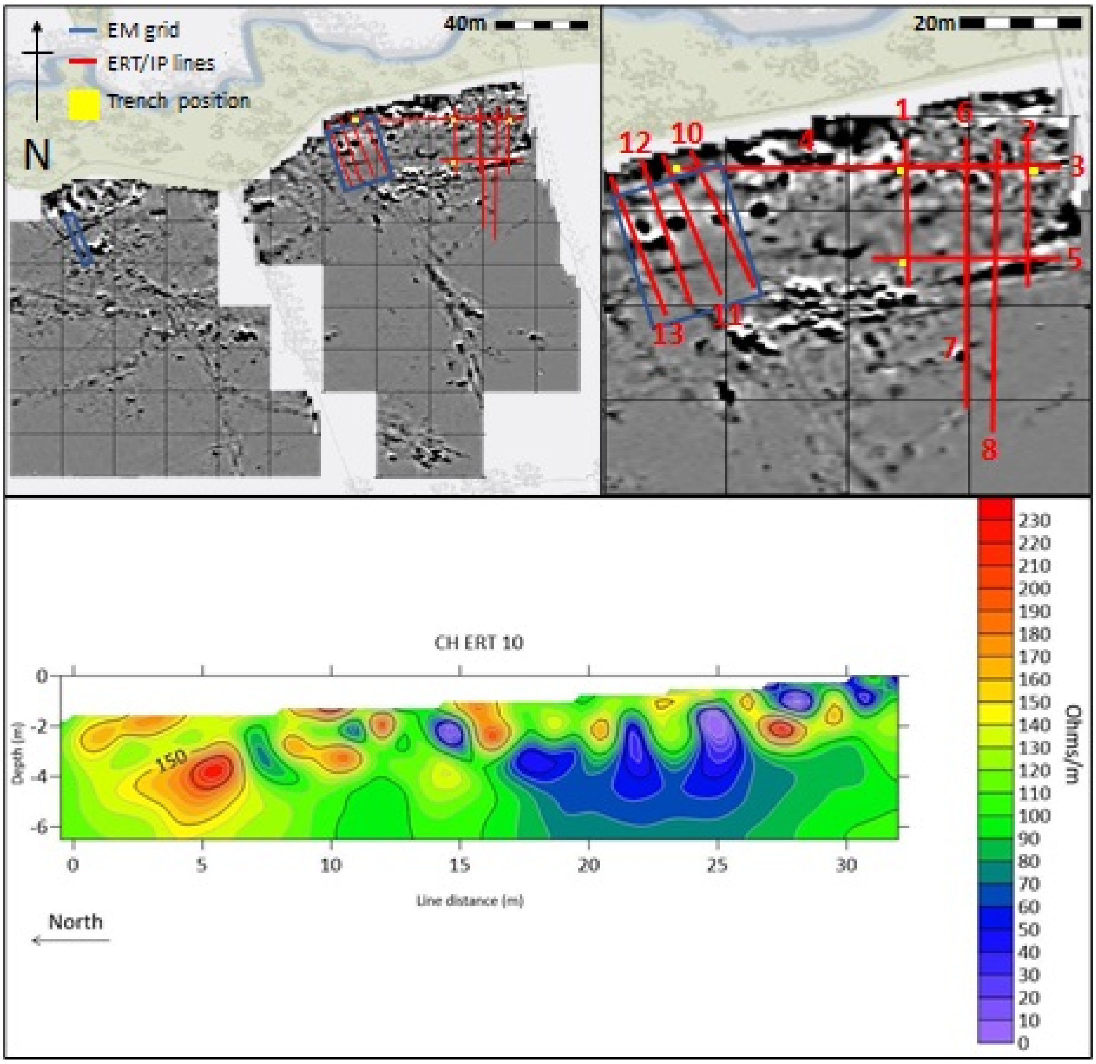


FIGURE 4.8: ERT/IP survey line positions with example ERT data

on interpretations from this project which covered an area extending across the smelting workshop into the technological waste deposit.

A total of 13 lines were surveyed using Earth Resistivity Tomography. The raw survey data is set out in Appendix A.1.2. Earth Resistivity Tomography survey lines 1 to 8 were carried out in 2016 in a grid format in the northeast corner of field 2. Lines 10 to 13 were completed in the summer of 2017 north of field 2. These surveys detected a number of anomalies of varying resistivity distributed across all survey areas. The interpretation of these surveys is set out in section 4.3.2.

4.2.3 Induced Polarisation

The use of Induced Polarisation in the mining industry to identify disseminated ores, including iron ores, shows this technique could be applicable to this case study in identifying this specific material, primarily in the technological waste deposit. As discussed in Chapter 3 this data is collected at the same time as the ERT survey, also giving a vertical slice through the ground. Using this technique at Chitcombe therefore helps to fulfil one of the aims of this project.

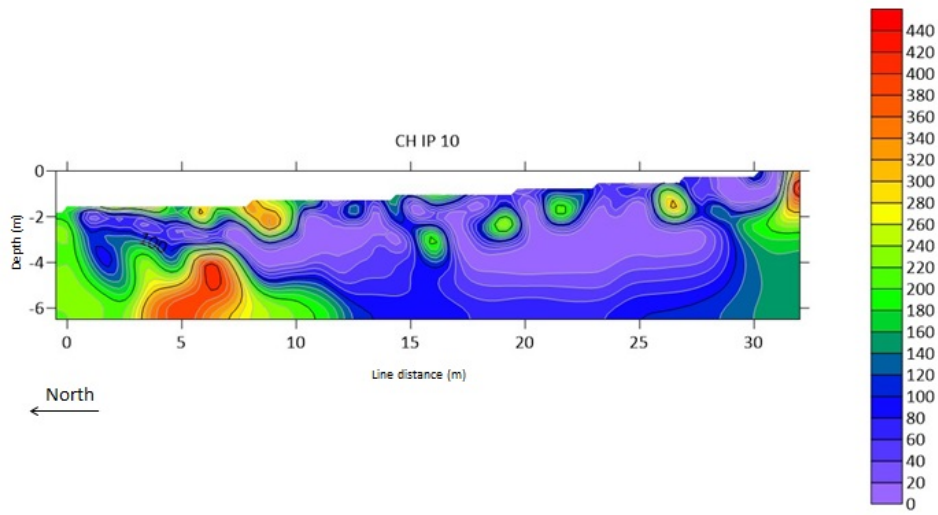


FIGURE 4.9: Example of raw IP data (Line 10) from Chitcombe

The induced polarisation surveys were completed across the site in two periods the first in the summer of 2016, the second in the summer of 2017. These were completed using the ZZ FlasRes64, utilising two different electrode spacing, 1m and 0.5m. These give survey line lengths of 64m and 32m respectfully, and were completed across the same area as the earth resistivity tomography surveys based on the same interpretation.

A total of 13 lines were surveyed using Induced Polarisation in the same positions and time-frame as the ERT surveys (fig 4.8). The raw survey data is set out in Appendix A.1.3. These surveys detected a number of anomalies of varying polarisation distributed across all survey areas; an example of the data can be seen in figure 4.9. The interpretation of the IP surveys can be seen in section 4.3.3.

4.2.4 Electromagnetic

The scientific framework and characteristics detected with the Electromagnetic surveys, as set out in Chapter 3, show this technique to be highly applicable to the investigation of iron production sites. EM surveys were used at Chitcombe as it met the aims of this project in mapping features in both the horizontal and vertical plane. Moreover, as an approach that is not commonly used on archaeological sites, its use in this project allows for it to be tested and a database started.

The electromagnetic surveys were completed across the site in the summer of 2017. These were completed using a GSSI EMP400. In-phase and quadrature

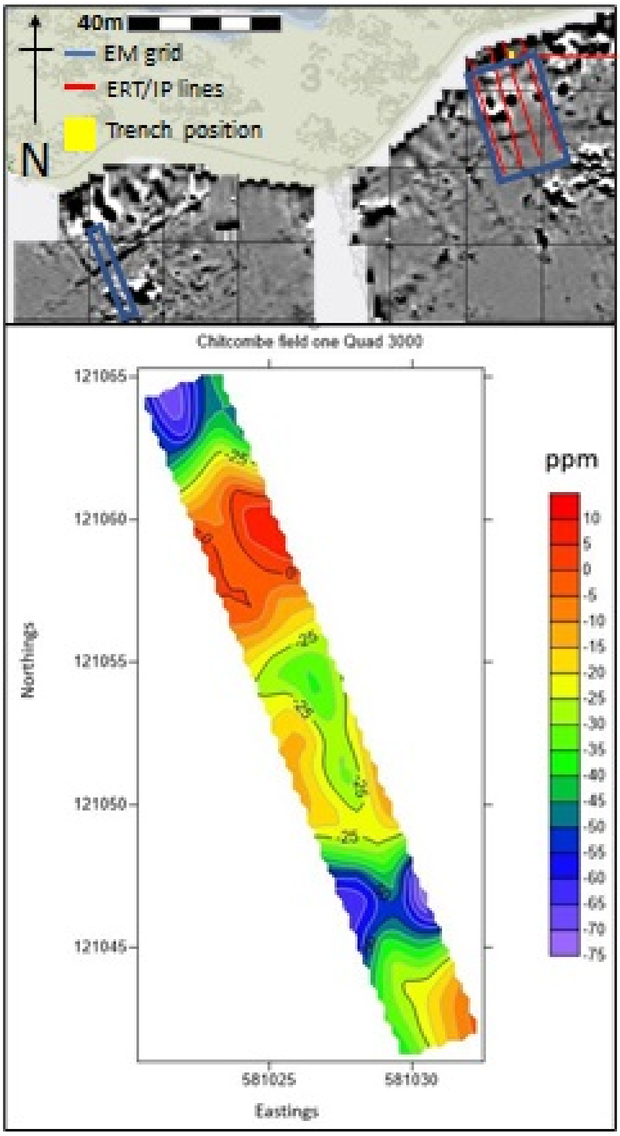


FIGURE 4.10: EM in-phase and quadrature survey grids, with example dataset (quadrature F1 3kHz)

were both recorded at 3kHz and 15kHz. The north of field 1 and 2 were investigated based on interpretations from previous surveys and excavation in this project (fig 4.10).

Survey 1 (F1) and Survey 2 (F2) covered areas of 30mx3m and 19mx30m respectively, on a slight Northwest/Southeast alignment. F1 took place in the north of field 1 and F2 took place in the north of field 2. The raw survey data is set out in Appendix A.1.4, with Four datasets and survey images created for each survey. The in-phase surveys show a number of anomalies of varying magnetic susceptibility spread across all surveys with F1 having more specific discreet anomalies and F2 showing a larger area of changing magnetic susceptibility with a bias towards increased readings to the south. The quadrature survey shows a number of anomalies of varying conductivity. In F1 this conductivity is positioned in more discreet anomalies and in F2 the survey shows lower conductivity to the north increasing to the south. A more in-depth interpretation will be set out in section 4.3.4 and 4.3.5.

4.3 Interpretation of Primary Datasets

All raw data, as seen in Appendix A.1, has been normalised and annotated with an accompanying form setting out key anomalies, other observations, and associations. These can all be found in Appendix A.2.

The normalisation of the data is different for the different surveys types and will therefore be discussed in their individual subsections. Only a single example from ERT, IP, EM in-phase and EM quadrature will be covered in this section as an example to give a more in-depth understanding of how the data has been interpreted. All other interpreted survey data can be found in Appendix A.2 and understood due to discussions in this chapter. This data will be drawn on in chapter 8 where the survey types will be drawn together in order to analyse and compare responses to the key anomalies. The entire magnetometry surveys will be interpreted in this section as it gives a full overview of the features at Chitcombe allowing the reader to understand the positioning and interpretation of all other survey types.

Key anomalies are those which will play an important role in the discussion and interpretation of the application of geo-prospection surveys and the organisation of iron production sites, all of which will be analysed in full in chapter 8. These include the technological waste deposit (TWD), furnaces, ditches and working areas.

4.3.1 Magnetometry

A number of data processing steps were carried out on the raw magnetometry data to standardise the data for better comparison and understanding. This included 'zero mean grid', 'zero mean traverse', and 'interpolate' in the X and Y axis. The data was then clipped to +/-100nT.

All three fields will be interpreted to give a full overview of the site at Chitcombe compiled into a single image (fig 4.11). Each field can be found individually in appendix A.2.1.

Across the surveys, anomalies have been highlighted and assigned a colour which refers to their interpretation. These categories are named in the key in figure 4.11 with most being self explanatory. Red represents furnaces, yellow represents modern deposits mostly associated with metal gates and fences, green represents ditches or undefined linear features that are likely to represent ditches, and orange represent post-hole or pit type features. Purple represent trackways. These consist of a mix of anomalies and are better pictures as a farmers trackway with a slag spread surface rather than a solid road. The light blue represents primary deposits of technological material. This refers to material associated with the process of smelting that is still interpreted as being in its initial deposition position. This mainly relates to the TWD, but also includes anomalies in working areas. The dark blue category represents secondary deposits of technological material. This refers to anomalies that have been interpreted as being caused by technological material but has been redeposited across the sites either accidentally or purposefully.

Furnaces (Red)

Across the site there are eight interpreted furnaces highlighted in red. Four of these are in field 1 and four in field 2. These are all positioned on the northern edge of the site where the land drops down to a ghyll and stream. The magnetic dipoles that form the furnaces have readings of up to 780nT, with readings around them of -860nT. These are very high magnetic responses which is expected from furnaces due to the high temperatures involved and the potential magnetic materials present. The positioning of these furnaces is also expected near to the edge of the ghyll where the TWD is positioned but what is interesting is their organisation in a line.

Ditch/Linear (Green)

There are a number of ditches and unidentified linear features across the site.

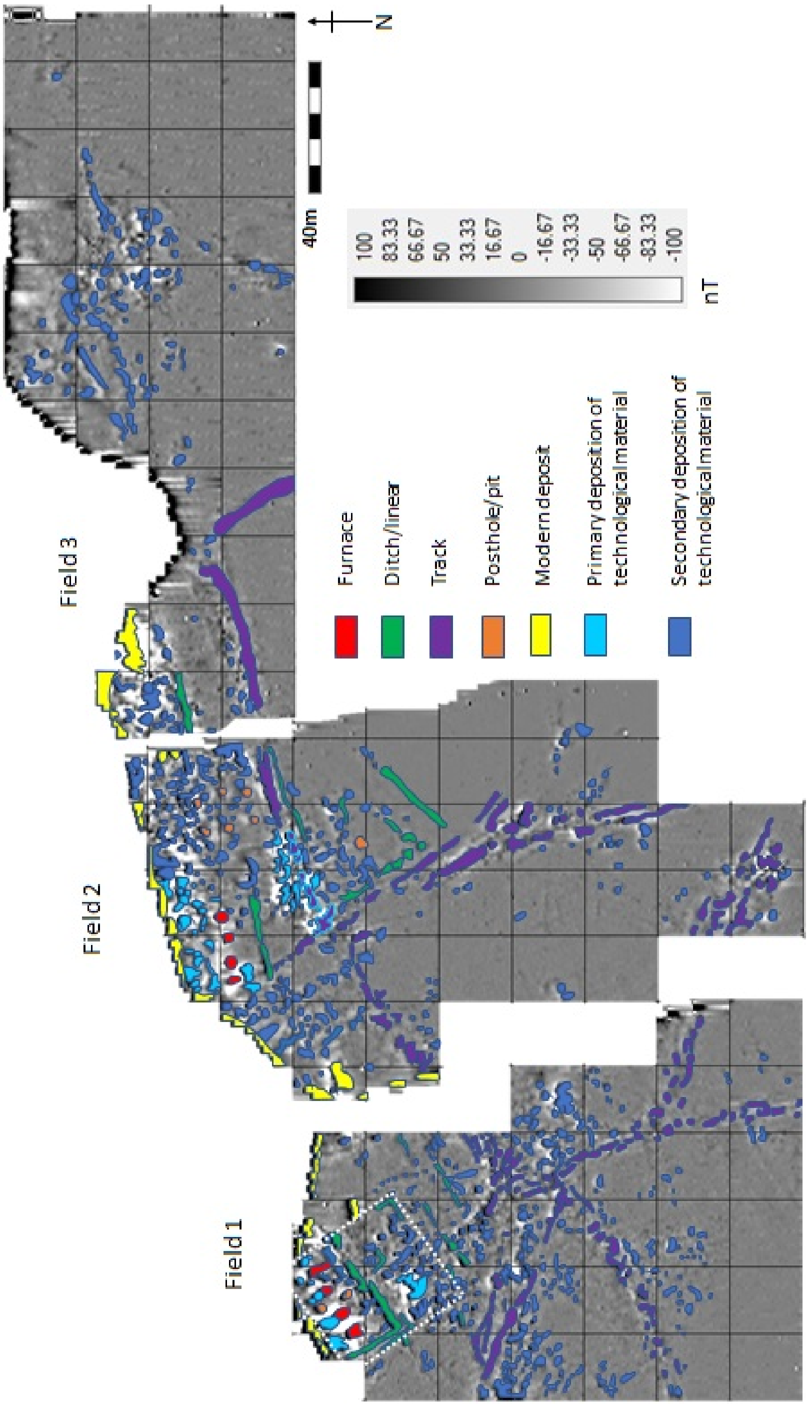


FIGURE 4.11: Interpretation of Chitcombe field 1 and 2 magnetometry survey

These features tend to be grouped in areas or associated with other features which assists with their interpretation. The first set to be discussed are in the north end of field 1. The dominant linear feature in this area forms a large 'L' shape wrapping around the west and south side of the furnaces with readings up to 163nT. This has been interpreted as a large ditch which helps to define the extent of the smelting workshop. There are two further smaller right angle anomalies coloured green to the south and south east of the smelting workshop within an area demarcated by a dotted white line. This whole area has been interpreted as a working area associated with the smelting process with these further right angle features representing additional ditches marking the area or the remains of structures.

At the north end of field 2 is a linear feature that runs in an east-west direction to the south of the set of four furnaces. This also has been interpreted as a ditch that represents the limit of the smelting workshop in this area. There are no clear returns to this ditch like in field 1 but there are a number of reasons for this including fill and size of the ditch and various taphonomic processes.

The last set of linear anomalies is in an area in the middle of field 2 to the south of the track. The first are two long and thin anomalies that run directly parallel to the track. This can be interpreted as a small ditch associated with the track, probably for drainage and run-off purposes. The next is a set of individual anomalies that form a right angle with another linear feature to the south. The coherent linear feature has very low readings. This area has been interpreted as a form of enclosure with activity that is not interpreted as smelting, this could be living space or administration, the track to the north of this area being a boundary between smelting and non-smelting.

Primary deposition of technological material (Light blue)

There are three main areas across the site that have been interpreted to contain primary deposition. The first of these is in field 1 and exists in the smelting workshop and working area. The anomalies in the smelting workshop are positioned to the north of the furnaces and are believed to represent deposits at the front and opening of the furnace and the TWD. The single anomaly in the working area in field 1, just to the south of the smelting workshop, has a high reading of 412nT. Due to its high readings it is not believed to be re-deposited material but rather in-situ. A possible interpretation for this is a deposit of roasted iron ore which would be highly magnetic. This adds to the interpretation of the working area where material is prepared for the smelt.

The next area is in the north of field 2, mainly to the north of the furnaces. This area represents the TWD and will be a key area of investigation through this project including further surveys and excavation. The anomalies to the south of the western-most furnace in field 2 has very high magnetism and has been interpreted as a possible deposit of roasted iron ore left beside the furnace.

The final area is south of the smelting workshop in field 2, being positioned on and to the north of the trackway. Due to the high magnetism across the anomalies in this area is it believed they are still in-situ as moving the material would cause a lowering in the magnetism due to mixing and realignment. There are no clear structures in the direct area. However, this is a busy area of the site with many other features nearby. The two possible interpretations for this is a large amount of roasted ore where it was brought into the site and deposited, or an area where some form of smithing was occurring which would produce highly magnetic hammerscale. Only further investigation would answer which one.

Secondary deposition of technological material (Dark blue)

Much of the secondary deposition anomalies across the site can be interpreted as accidental movement or deposition of material as well as movement due to more recent processes such as ploughing. However, an area that might be of interest is in the north-east of field 2 to the east of the furnace workshop and north of the track. This area of the site has previously been identified as representing the TWD (Hodgkinson, 1988), however, as can be seen in the ERT and IP surveys along with excavations this is not seen to be the case but has instead been interpreted as a possible made surface. This interpretation will be discussed more in-depth in chapter 10.

Track (Purple)

There are a number of trackways that have been identified on the site and are formed from a number of different anomalies of varying readings. These variations in readings could show a variation in the building material, which would be expected if technological waste is being used or the degradation of the track due to taphonomic processes. However, there are a number of examples of longer anomalies that could represent better constructed or preserved stretches of the trackways. In field 1 there are three main trackways heading from the northwest, southwest and south, all converging on the same location in the centre-right of the field. A trackway must also join this central area from field 2. In field 2 there are two main trackways,one heading in an east-west direction from field 1 and one heading in a north-south direction. The east-west track in field 2 shows the strongest response to the magnetometry survey at its eastern extent. This part of the track is in a busy area of the site including possible structures, working areas and enclosures. This could show the track in this area has been constructed in a more formative way marking the main access to and from the site. The number of tracks heading to and from this site show the potential for it being an important hub in the landscape.

Post-hole/Pit (Orange)

A number of anomalies have been identified as potential pits or post-holes on the site. The first to be discussed will be the two present in the smelting workshop in field 1. These are positioned slightly in-front of and behind the line of the furnaces with readings of up to 425nT. The readings are such that these could be mistaken for furnaces but it is believed they represent post-holes or pits due to their positioning. These could represent part of a large structure within the smelting workshop or the positioning of a smithing stump.

The second are six anomalies forming a rectangular shape in the north-east of field two. These were difficult to interpret due to the large volume of secondary deposition around them but due to their form and regular spacing they have been interpreted as large post-holes. This interpretation then leads to the idea that there could be a large structure in this area of the site.

The last is a single anomaly in the centre of the enclosure to the south of the track in field 2. It is unclear what this feature might be but its form and position meant it has been interpreted in this category.

Modern (Yellow)

The yellow anomalies all represent modern structures. Those along the northern edge of field 1 and 2, and western edge of field 2 caused by metal fencing. The two anomalies on the eastern side of field two are caused by a metal gate into the next field, and the large anomaly on the west side of field 2 is a modern deposit of hardcore that is part of a gateway in this area between field 1 and 2.

4.3.2 Earth Resistivity Tomography

To normalise the survey data for earth resistivity tomography the scale was set to 0-380 Ωm for every image. This is the maximum scale range across Chitcombe. By normalising the survey images the colour scale is the same throughout all surveys making anomalies of a specific reading easier to compare.

The example being used to discuss the Earth resistivity tomography is Line 10 (Appendix, Fig4.12) with all other ERT survey lines being presented in Appendix A.2.2. The interpretation figure consists of a normalised survey at the top with scale bar so the true data readings of the anomalies can be seen. The lower survey is an interpretation overlay with anomalies marked and identified by colours which are in a key below. Both these survey lines are to scale so can easily be compared.

Line 10 has seven types of anomaly present which will be outlined here and then discussed specific to the survey. Many of the categories are self explanatory. The light blue represents the technological waste deposit, an in-situ deposit consisting of slag, furnace material, geological material and other small amounts of archaeological material, and a key feature throughout this thesis. The light blue represents a ditch which has been infilled with a low resistivity material. The red represents increased resistivity anomalies associated with the structure of a furnace. The pink represents a lower resistivity interior of the furnace. The light grey represents general geology and the space between anomalies that cannot be interpreted due to the halo effect of how the data is collected. Other categories not present in this example but that can be found in a number of other surveys is yellow, which represents modern deposits, and gold which represents uncertain archaeology/geology. These anomalies are often at the depth extent of known archaeology.

The dark blue and light green categories represent 'undifferentiated archaeological deposits' (UAD) with the dark blue being 'primary' and the light green being 'intrusive/infill'. These two broad categories represent a large proportion of the interpretation across the surveys, incorporating a full range of readings. They are neither underlying geology nor specific features, such as represented by the other colour categories, but are of anthropogenic origin. The primary anomalies, coloured dark blue, are categorised by increased resistivity often, but not in all cases, forming a spread of data with a number of anomalies which are outlined in the interpretation overlay. The intrusive/infill anomalies, coloured light green, are categorised by lower resistivity and more often represent a single anomaly. There is a wide range of potential interpretations of these deposits including scattered spreads of technological debris, deliberate or accumulated surfaces, or structural elements such as postholes, pits and ditches. Future analysis of the data and the archaeology could resolve their interpretation but that work is beyond the scope of this research and here the term 'undifferentiated deposit' identifies them as archaeology and categorises them for wider interpretation.

Three key features have been identified in line 10. The first in the technological waste deposit, coloured light blue, at the north of the line with measurements between 120-230 Ωm, and a depth of around 4m. The true depth of this deposit is believed to be nearer to 2m with the haloing effect of the data collection increasing its apparent depth. This was chosen as a key anomaly for this project as it represents the technological waste deposit. An area of the iron production site whose investigation is needed to meet the aims of this project. The readings across this anomaly are not uniform with areas of higher and lower resistivity. This would be expected in a technological waste deposit as a variety of material is being deposited in differing quantities and place. The interpretation of this anomaly is helped by responses from the magnetometer survey and in-field observations

The next is the furnace, coloured red and pink, a complex structure of anomalies positioned between 7-17m laterally with readings between 0-190 Ωm, and a depth of up to 2m. This feature consists of two areas, one centred on 10m consisting of three red furnace anomalies and one pink fill, the second is centred on 15m and consists of two red furnace anomalies and one pink fill. The

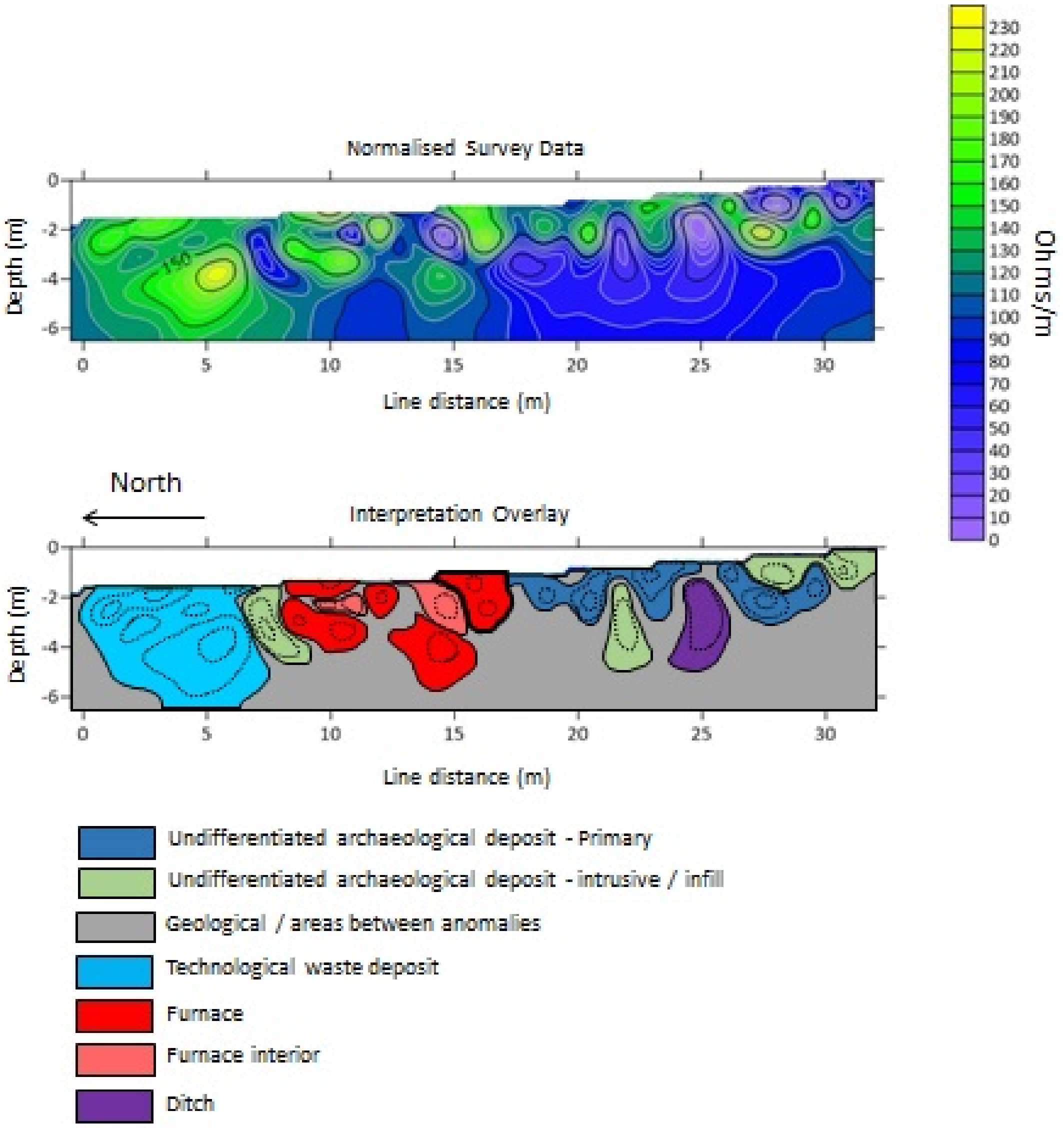


FIGURE 4.12: Interpretation of Chitcombe ERT line 10

anomalies at 15m represent the main structure of the furnace, which is confirmed through the magnetometry data (fig 4.8). The red anomalies have been interpreted as representing the back structure of the furnace to the south and the base of the furnace with lower resistivity pink internal material open to the north which is the direction of the technological waste deposit. The anomalies centred on 10m have a very similar form in structure, but have an unclear representation on the mag surveys. These have been interpreted as part of the furnace structure with two main options. The first being that these are the remnants of an older furnace that was then rebuilt to the south, which is the structure at 15m. The preferred interpretation is that this is the extended structure at the front of the furnace associated with its opening and tapping/working area.

This was chosen as a key anomaly as the furnace is a key feature of an iron production site, and its identification within the surveys meets the aims of this project to identify the organisation of the site and testing methods to investigate the structure of features on the site.

Finally is the ditch, coloured purple, a single anomaly centred on 25m, descending from the near surface with readings below 30 Ωm. . The lower resistivity response would be expected from this type of feature as the ditch becomes filled with more organic material that holds more water than the surrounding natural geology or fills. The bottom of this anomaly is unclear as the natural clay geology across the site has a low resistivity. This ditch encloses the furnaces and forms the boundary of the smelting workshop. The interpretation of this anomaly is helped by the response from the magnetometer survey (fig 4.8, fig 4.11). This was chosen as a key anomaly as a ditch is a common feature on Roman sites and an understanding of its form could assist with other interpretations. Moreover, this ditch identifies the smelting workshop which plays a key role in the discussion of organisation and interpretation of the site.

Another observation that can be made about line 10 is the lower resistivity response from the natural clay geology in the lower sections of the survey and represented by the grey category.

The undifferentiated archaeological deposits form most of the anomalies to the south of the furnace. The interesting observation here is the area between the furnace, coloured red, and ditch, coloured purple, as this is in the smelting workshop and shows a potential build up of material or un-interpreted features.

4.3.3 Induced Polarisation

To normalise the survey images for induced polarisation the scale was set to 0-920 SI. 920 SI is the mean value of all the highest responses from the survey lines at Chitcombe.

A modern deposit in a gateway, present in line 4 (fig A.54), along with a small number of other anomalies, have such high induced polarisation readings, up to 2300 SI, that definition has been lost in the predominant lower polarisation anomalies. By normalising the survey images the colour scale is the same throughout all surveys making anomalies of a specific reading easier to compare.

The example being used to discuss the Induced Polarisation surveys is Line 12 (Fig4.13), with all other IP survey lines interpreted in Appendix A.2.3.

The interpretation image and categories are the same as set out in the previous section for ERT. This is due to the fact that the survey data is collected at the same time and the data produced in the same form of image.

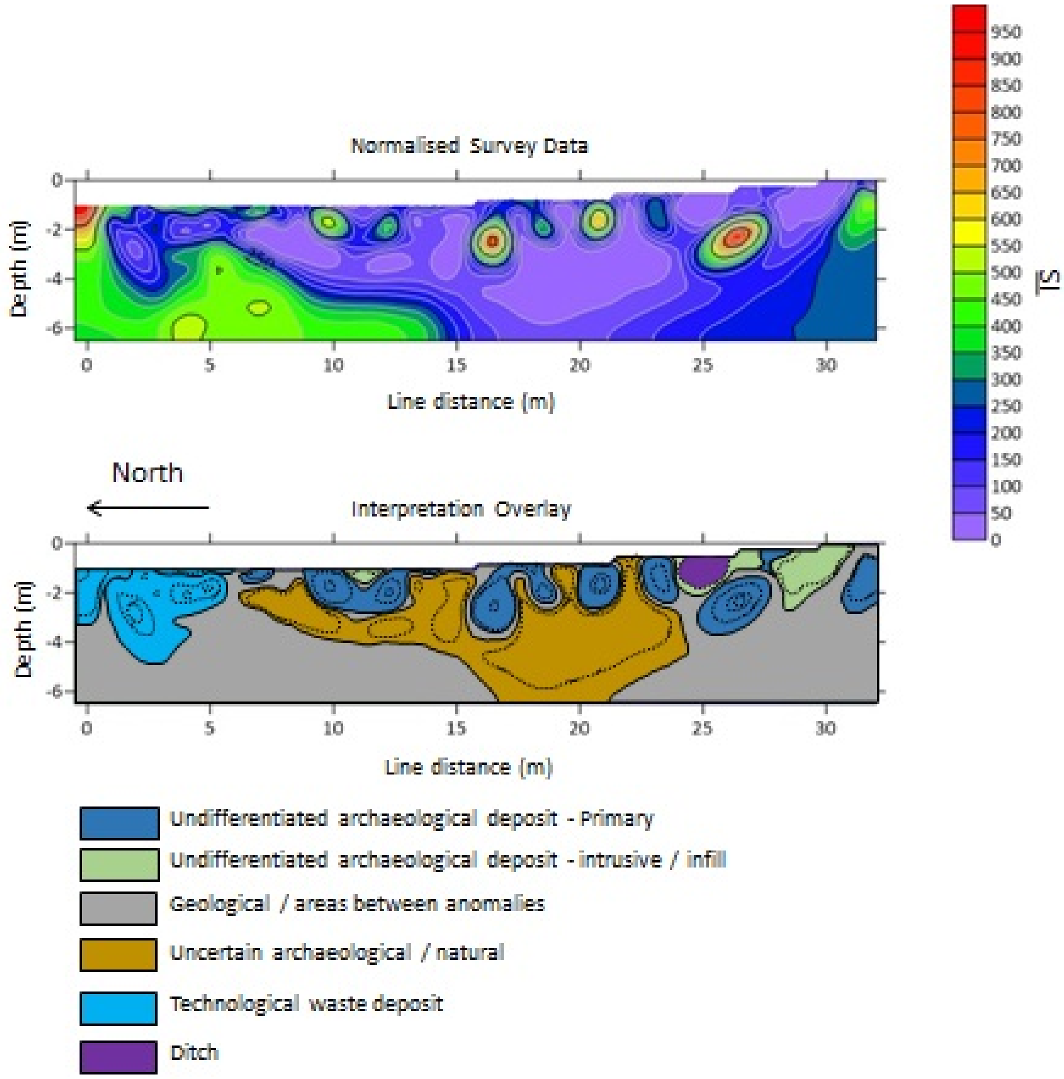


FIGURE 4.13: Interpretation of Chitcombe IP line 12

Two key anomalies were picked out on this line. The first is the TWD, coloured light blue, at the north end of the survey from 0m to 6m. This is formed of two main areas. The first is positioned at ground surface at 0m, and has a reading up to 950 SI. The second is an area from 1-5m with lower readings between 0-100 SI and consists of a number of smaller anomalies. As the waste heaps are heterogeneous in their composition it would be expected to have a variety in readings.

The second is a ditch, coloured purple, which is positioned at 25m laterally, descending from the ground surface as a single anomaly with a reading of 0 SI showing it is a coherent deposit of non-responsive material. It is unclear if the primary deposit just to the north of the ditch is part of its formation, but until it can be further investigated it has not been included. The interpretation of this anomaly is helped by responses from the magnetometry and ERT survey which will be further explored in chapter 8. As discussed the ditch is a key feature as it forms the smelting workshop and is prevalent on archaeological sites.

Between the TWD and ditch is a number of Primary UAD's along with a large expanse of uncertain archaeology/natural. The trouble with the interpretation of this category is that in IP there are large expanses of non-reactive material that start on the ground surface and descend to below the level of archaeology with no definition. It is therefore difficult to interpret which parts, if any, of these large anomalies are archaeological or geological, but from its position, with part of it near or on the ground surface, it is believed to consist of archaeology.

4.3.4 Electromagnetic - In-phase

The in-phase surveys have been normalised on a maximum/minimum scale for each frequencies. The 15kHz surveys between 1714-16433ppm and the 3kHz survey from -1916-13191ppm.

The in-phase surveys from field 1 will be used here as an example with the main discussion being based on the 15kHz survey (fig 4.14). All other interpreted Em surveys can be found in AppendixA.2.4.

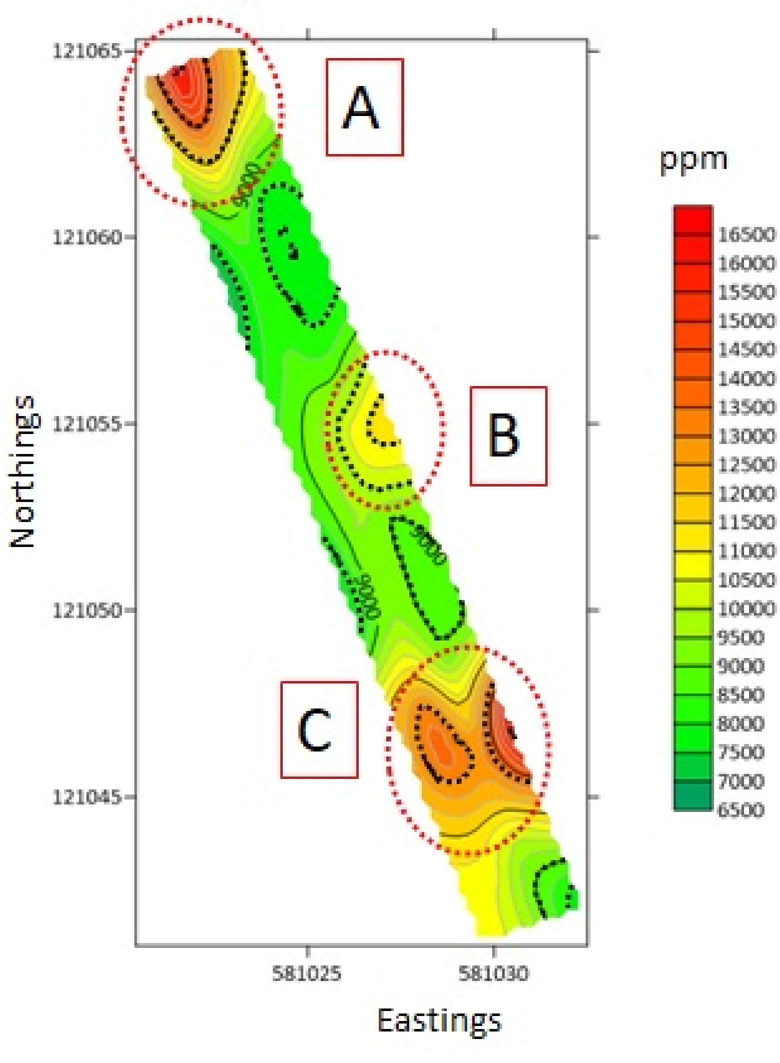


FIGURE 4.14: Interpretation of Chitcombe field 1 in-phase 15kHz

Three key anomalies were identified in the 15kHz survey. The first of these (A) is positioned at the north end of the survey and at 581022E,121064N. It has increased magnetic susceptibility with a reading of 16500ppm. This anomaly has been interpreted as part of a furnace. This would be expected as intense burning and the material used and produced in smelting is magnetic and is the standard response from a furnace. This is confirmed by the magnetometer survey which will be analysed in more depth in chapter 8.

Anomaly (B) has increased magnetic susceptibility measuring up to 12000ppm on the eastern side of the survey centred on 581027E,121055N being demarcated by the dotted black line around the yellow area. With information from the magnetometer survey this anomaly represents the ditch that defines the smelting workshop. However, as this anomaly does not extend across the entire survey, it would be more accurate to identify this anomaly as a specific deposit within the ditch rather than the ditch itself. This shows the different information that can be gained through the use of different surveys and how they assist with interpretation.

Anomaly (C), centred on 581030E,121047N, is formed of two increased points of magnetic susceptibility, the western measuring up to 13500ppm and the eastern 16000ppm. This is in the same position as a large primary magnetic anomaly in the magnetometer survey (fig 4.11), which has been interpreted as part of a working area.

Throughout the rest of the 15kHz survey the readings range between 6500-9000ppm. These areas between anomalies A and B, and B and C, represent space within the working areas. The responses are being caused by undifferentiated archaeological deposits with potential influence from the natural geology.

The 15kHz (AppendixA.2.4,FigA.63) and 3kHz (AppendixA.2.4, FigA.64 surveys are directly associated as they are conducted simultaneously. As set out in depth in Chapter 3, the data is collected in the EM survey as an average of the volume of the ground surveyed. As higher frequencies attenuate faster than lower frequencies, in the case of this survey the 3kHz survey will penetrate deeper into the ground than the 15kHz survey. By comparing the two survey frequencies it can be seen that the 15kHz survey is about 3000ppm higher than the 3kHz survey. Due to the fact that the anomalies match between the two surveys it can be interpreted that the source of the response is nearer the ground surface as it is more dominant in the 15kHz survey.

4.3.5 Electromagnetic - Quadrature

The quadrature surveys have been normalised on a maximum/minimum scale for each of the frequencies.The 15kHz surveys were normalised to between -104-405 ppm and the 3kHz survey from -75-72 ppm.

The quadrature surveys from field 1 will be used here as an example with the main discussion being based on the 15kHz survey (fig 4.15). All other interpreted surveys can be found in AppendixA.2.4. All key anomalies are in the same position as in the in-phase, and have therefore been identified for the same reasons, but their response to the quadrature surveys will be discussed here.

Three key anomalies were identified in the 15kHz survey. Anomaly (A) is an area of decreased conductivity, with readings down to 0 ppm, to the north of

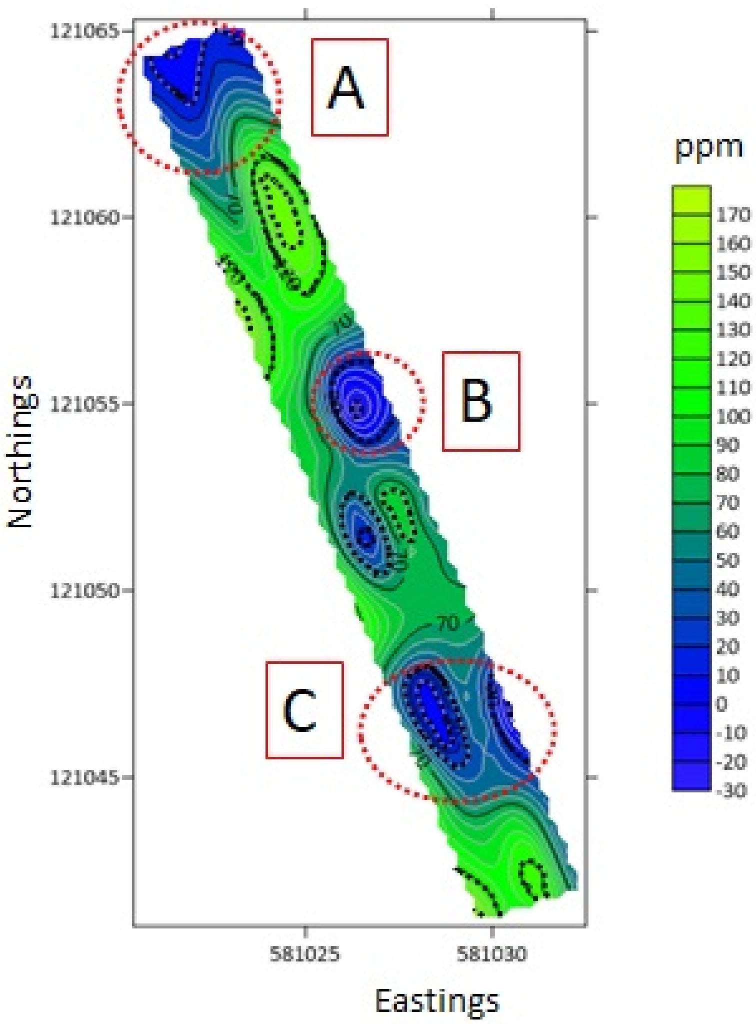


FIGURE 4.15: Interpretation of Chitcombe field 1 quadrature 15kHz

the survey (581022E, 121064N). The possible reasons for changes in conductivity on an archaeological site were discussed in chapter 3. With the information from the magnetometry and in-phase surveys this anomaly can be interpreted as representing part of a furnace.

Anomaly (B) has decreased conductivity measuring down to -20 ppm at its centre, positioned at 581026E, 121055N. As with the in-phase survey this is interpreted as a deposit within the smelting workshop ditch, being backed up by the magnetometry survey.

Anomaly (C), centred on 581030E,121046N, is formed of two areas of decreased conductivity, the western area measuring down to 10 ppm and the eastern -10 ppm. This is in the same position as a large magnetic anomaly in the magnetometer survey in the working area.

The remaining areas in the survey all represent space within the working areas. The response here is given by undifferentiated archaeological deposits with influence from the top soil and natural geology. Most of the response in this area is between 70-120ppm, showing a fairly consistent range of reading, with the exception of an anomaly centred on 581026E, 121052N with readings of 20 ppm which could represent a pit or post-hole type feature.

As with the in-phase the 15kHz (AppendixA.2.4, FigA.67) and 3kHz (AppendixA.2.4, FigA.68) quadrature surveys are directly associated as they were conducted simultaneously, and are therefore directly comparable with more in-depth discussions taking place in Chapter 8

4.4 Discussion

The use of geophysical surveys to estimate the depth and volume of the waste deposits shows potential in this case study, but caution must be taken. In all 13 ERT (ap A.2.2) surveys the trend was to see higher resistivity on or near the ground surface, which was in many cases mimicked by the induced polarisation (ap A.2.3). Excavation showed that these responses to the surveys are caused by the technological waste of iron production (ap B.2). Overall, when comparing ERT and induced polarisation, it can be seen that there are similarities and differences. With a lot of these responses on or near the ground surface which are assumed to be in the archaeological deposits, it can be theorised that it is not the same material leading to high readings in the individual surveys but that they are both involved in the iron production process and therefore end up in the deposits together. These surveys also show promise in the assessment of these sites and others by showing the vertical cross sections of anomalies and features, giving investigators another level of information to inform and guide subsequent investigation.

The magnetometer survey (fig 4.11 has allowed for an understanding of the horizontal extent of the site and positioning of features within the site. However, care must be taken as there is a high possibility that the response to the technological waste deposit is enlarged due to re-deposition of the technological waste either for another use on site such as gravelling the floor, or by later activities such as ploughing.

The electromagnetic surveys covering in-phase and quadrature, give an added layer of information for interpretation in addition to of the standard magnetometry and resistivity. The first is the potential understanding of change of deposit with depth, which could be extended to theories on preservation of the site. At Chitcombe, a number of features are present in both the 15kHz and 3kHz in-phase or quadrature surveys. This shows, with a level of certainty,

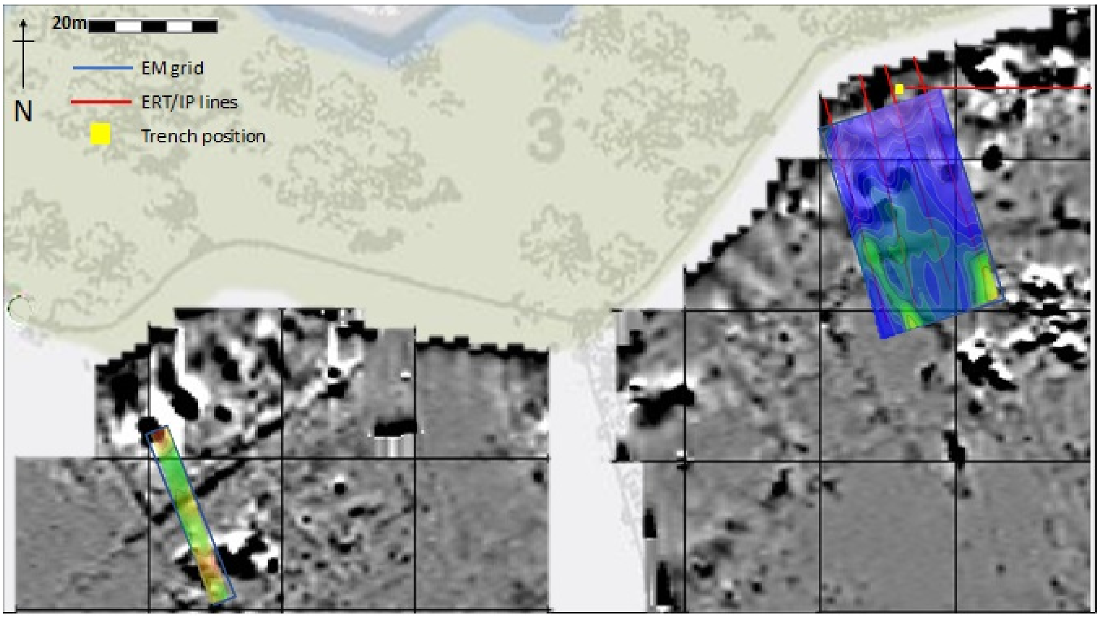


FIGURE 4.16: 3kHz over magnetometer survey

that these are extending deeper into the ground and preserved in-situ. These surveys also allow for understanding of how magnetic susceptibility and conductivity, and hence resistivity as it is the proportional inverse, are related. The in-phase can also be directly related to the magnetometer survey and the quadrature to the resistivity surveys, giving more information on the archaeological remains. An example of this is looking at the furnaces. In the magnetometer survey the furnaces show up as strong magnetic responses in both smelting workshops. However, when surveyed using in-phase the furnace in F1 showed as a strong magnetic susceptibility response whereas in F2 there is no response given by the furnaces (fig 4.16). This could bring into question the interpretation of the furnace, or whether they are apparatus for different processes in smelting. This will be discussed further in chapter 8.

5 Case Study 1 : Chitcombe - Part B - Excavation and Deposit Sampling

5.1 Introduction

Case study 1, Chitcombe, involved three major stages of investigation. Geo-prospection investigation of the site, excavation, and analysis of excavated materials. The geo-prospection investigation of the site was covered in chapter 4. This chapter will cover the excavation, deposit sampling, and material classification, along with analysis of the weights and classifications. The supporting datasets for this chapter can be found in Appendix B.

The background information for the site including location, and previous investigations of the site have been covered in the introduction section to chapter 4 so will not be repeated here.

It is important to note here that the excavations that took place at Chitcombe were all part of a project run by the Hastings Area Archaeological Research Group (HAARG) who kindly allowed this project to open 4 trenches in order to collect the data presented in this thesis. All other trenches, and associated material, are the intellectual property of HAARG.

Between 2016-17, a total of 30 trenches were excavated by HAARG across the site. The trenches were designed to look at a variety of different aspects of the site. An overview of all trenches including contexts and discussion is given in AppendixB.2. This chapter will look in detail at the four trenches, 1, 2, 13, and 14, which were excavated as part of this research project, using a purpose designed quantification strategy.

5.1.1 Aims and objectives

The aims set out here are the general aims for the case study and are therefore the same in Part A and B. The objectives are different as they are specific to the datasets being covered.

Aims:

- Understand the organisation of the Roman iron production site at Chitcombe.
- Test methods for investigating iron production sites to calculate the horizontal and vertical extent of deposits with a focus on the technological waste deposit.
- Quantify and characterise technological waste to gain a true understanding of what forms the technological waste deposits and the development and changes that occurred in technological processes.

Objectives:

- Excavate a number of test pits of known volume into the technological waste deposits to ground-truth the geo-prospection data.
- Excavate a number of test pits of known volume into the waste deposits to generate data sets of technological waste materials from which to quantify the makeup of the waste deposits.
- Analyse the technological waste on a macro scale to quantify and characterise, constituent volume, technological processes and dynamics of deposition.

5.2 Field Strategies and treatment of excavated materials

A number of trenches were excavated across this site forming datasets for analysis. The general approaches for excavations, deposit sampling, and classification are set out in chapter 3. How and why these strategies were applied to this case study will be set out in this section. All raw data collected can be seen in Appendix B. The excavation of the four trenches for this project happened over two distinct periods. The first in the summer of 2016 and the second in the autumn of the same year. This had a number of influences on the decision making for this project which will be discussed throughout this section.

5.2.1 Excavation and deposit sampling

As discussed in chapter 3, spit excavations were used to investigate the technological waste deposit in this case study rather than the standard context excavation. Context excavation was used in all other trenches excavated by HAARG. The use of spit excavation allowed for a standard and repeatable practice for the collection of technological waste to meet the aims of this project.

Excavation

Once excavations had started it was decided that the spits would have a depth of 0.1m in order to try and gain as high a resolution as possible through the waste deposits. This decision was reached as the majority of technical waste fragments were smaller 0.1m so there was less chance of large fragments spanning multiple spits spits. Trenches 1, 2, 13, and half of 14 were excavated in the summer of 2016, with trench 14 being finished off in the autumn of 2016. All spits were labelled using numbers in the summer and letters in the autumn to differentiate between the two periods.

The decision on assigning size categories was made prior to the first set of excavations. Standard archaeological sieves were deemed too small for this project, therefore custom sieves were made (fig5.1). The only mesh available at the time of construction was 6mm. This was therefore the size used to define large material (above 6mm) and mixed matrix (below 6mm). All material above 6mm was collected for analysis. For the mixed matrix, everything below 6mm, 10%wt was collected from each spit. The method for the excavation of the waste heaps is set out in full in AppendixB.1.

FIGURE 5.1: Custom made sieve and meter square

Treatment of spit material

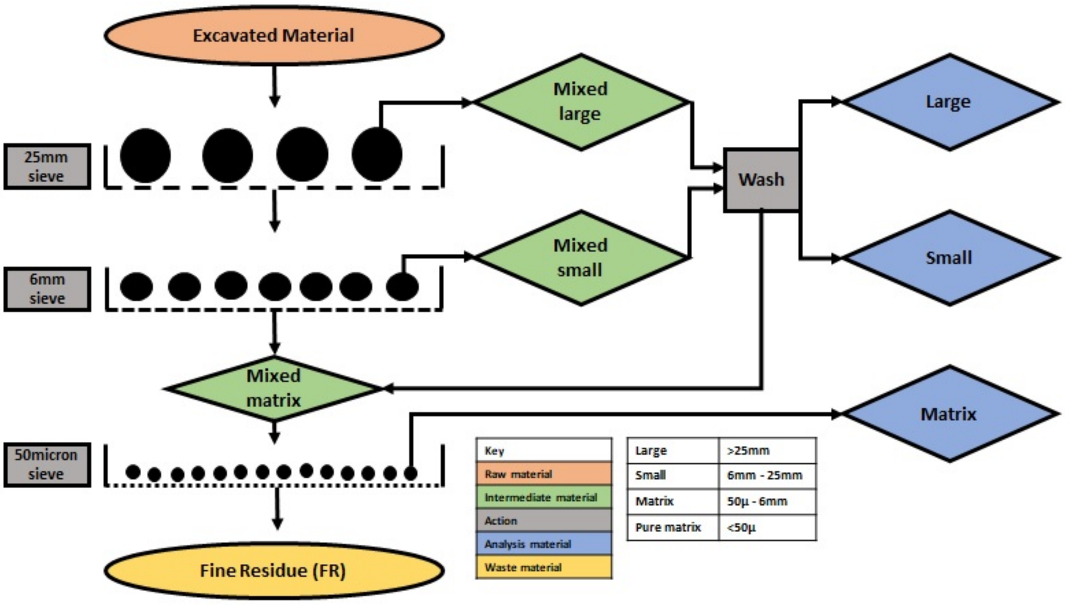


FIGURE 5.2: Excavation material collection schematic

The large material, measuring over 6mm, collected during the summer excavations was washed, by spit, and classification started. However, it was observed that the macro-morphic markers on the technological waste were better identified on the larger fragments, and the difficulties encountered in trying to wash off the very sticky Wealden clay, particularly on the smaller fragments, proved an unrealistically time-consuming exercise. As a result, it was noted the strategy for categorising material by size should be changed. However, there was no time to change the method before the autumn excavation. For this reason, all material above 6mm was collected but not washed so it could be passed through another sieve when available.

A 25mm sieve was introduced for the collected material from Chitcombe to be passed through. Rather than a large (above 6mm) and matrix (below 6mm) dataset, there were now mixed large (above 25mm), mixed small (between 25 and 6mm) and mixed matrix (below 6mm) datasets (fig 5.2).

Material collected from Chitcombe that was larger than 6mm was passed through the 25mm sieve off site. Due to material contained within, and time constraints in the project it was decided that only every other spit in trench 14 would be used. For trench 14 spits 1, 3, 5, and 7 this created the large and small categories. For trench 14 spits A, C, and E, this created the mixed large category which was then washed to calculate lost mixed matrix.

From the observations made during washing it was decided only the large category would be morphologically categorised, as these size fragments of technological waste contained the best macro-morphic markers, and the small and matrix categories would be used to understand the volume of materials, slag, furnace material and geological material, in the trench. Therefore a 1kg subsample was taken of the mixed small from spits A, C, and E, and mixed matrix

FIGURE 5.3: Large size category laid out by spit to be washed and dried

material from each spit. In spits 1, 3, 5, and 7 the small category had already been separated so complete values are known. The mixed small and mixed matrix material was washed through 50μ netting. The weights from the 1kg sub-samples were then extrapolated to give an interpretation of material in each spit. This will be discussed in more detail in the quantification section of this chapter.

5.2.2 Classification of materials

Once all material had been washed (fig5.3) it was stored according to spit and size category ready for classification. All size categories were dealt with a

FIGURE 5.4: Sorting of large size category into types

spit at a time. The large category was emptied into a sorting area and manually split into types (fig5.4) according to a number of physical factors. The types created were not pre-determined. The physical factors included material type, surface textures, and a number of other factors which were then recorded across the group on a proforma sheet. The reasons for each of these categories has been set out in chapter 3. Examples and descriptions of the types can be found in AppendixB.4.

The small and matrix were only split into material categories (slag, furnace material, and geological) for quantification purposes, with notes taken on anything that was identified as unique, for example spheroidal slag.

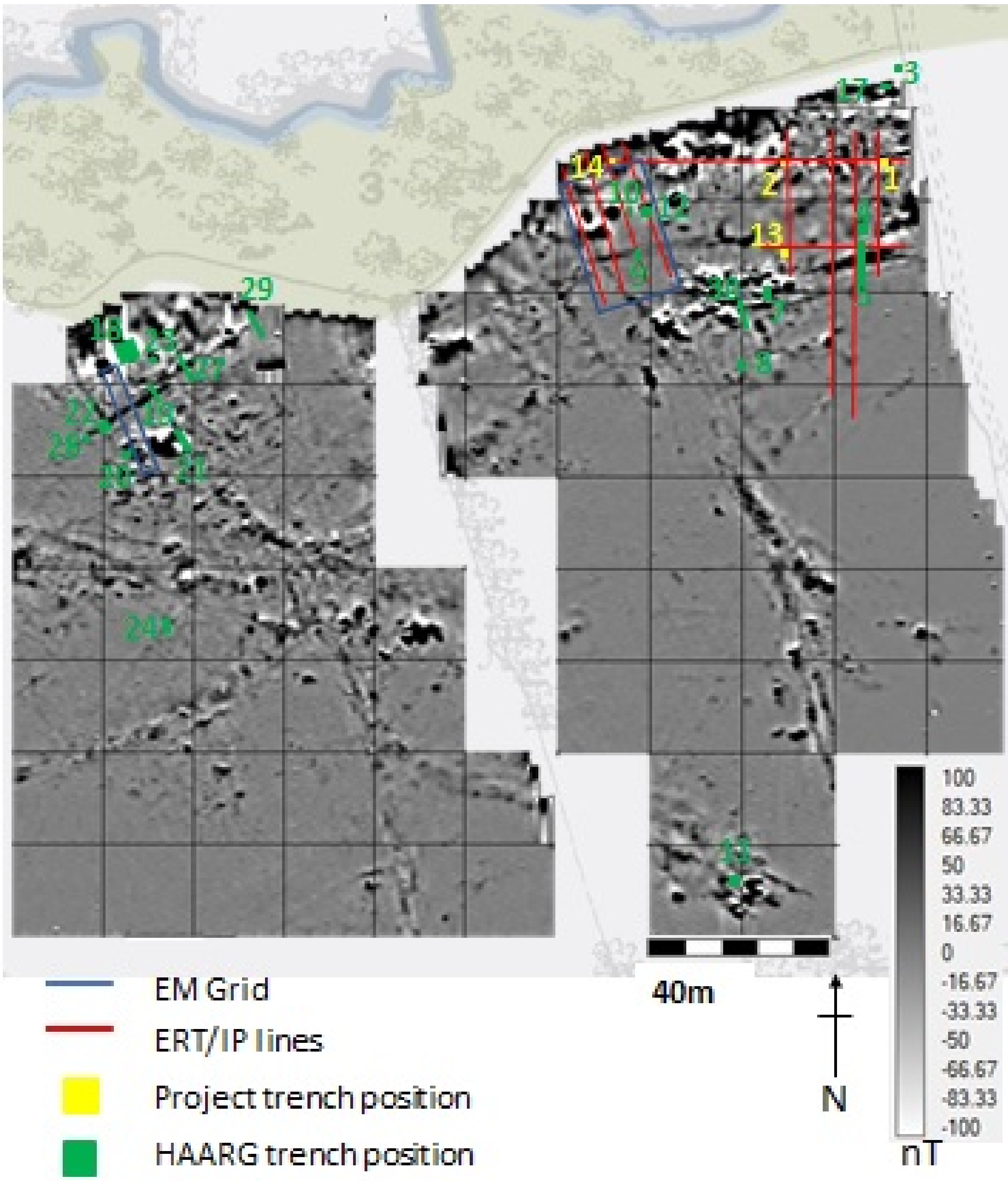


FIGURE 5.5: Position map of trenches excavated at Chitcombe showing ERT/IP and EM grids over magnetometry data

5.3 Discussion of Primary Datasets

A number of datasets have been created throughout the excavation. This includes trench information, weight information by material, size, and type (AppendixB.3, and classification data (AppendixB.5). Examples of the data will be discussed in this section.

5.3.1 Trench overview

A description of all 30 trenches can be found in Appendix B.2 and their position across Chitcombe seen in figure 5.5. This section will outline the 4 trenches excavated for this project.

Trench 1

Trench 1 (fig5.6) measured 1x1m and had a maximum depth of 0.55m, giving a volume of 0.55m^3. Within this trench two contexts were identified, 101, and 102, and the trench was excavated in two spits (fig5.7). This trench was excavated into an area that was believed to represent part of the technological waste deposits present on the site. A full range of technological waste was discovered in this trench. The total weight of material removed from T1 was 233.90kg. Of this 175.25kg was matrix and 58.65kg technological debris (ap B.32).

FIGURE 5.6: Section with spit lines of T1, Chitcombe

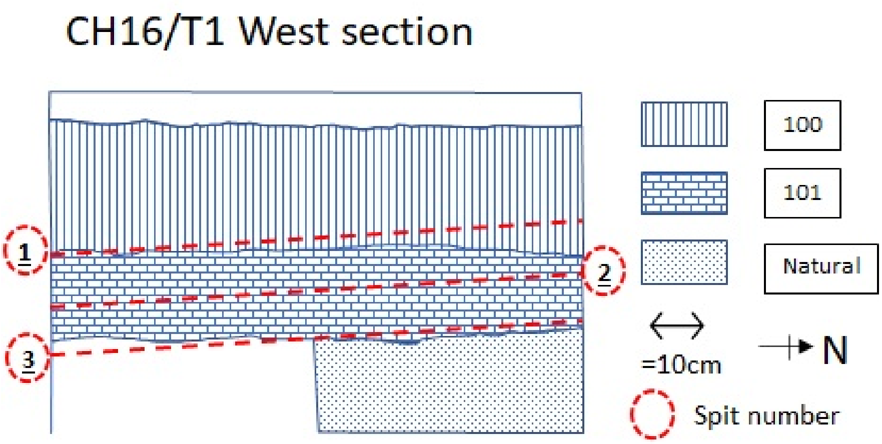


FIGURE 5.7: West section of trench 1, Chitcombe

Trench 2

Trench 2 (fig5.8) measured 1x1m and had a maximum depth of 0.70m, giving a volume of $0.7m^3$. Within this trench there were six contexts (201, 202, 203, 204, 205, 206), and was excavated in six spits (fig5.9). This trench was excavated into an area that was believed to represent part of the technological waste deposits. A full range of technological waste was discovered in this trench. At the base of the trench, on the natural clay geology was a Victorian land-drain indicating the Roman deposits in the trench were disturbed. The total weight of material removed from T2 was 787.00kg consisting of 535.60kg of matrix and 251.40kg of technological debris (ap B.32).

FIGURE 5.8: Base of T2 with Victorian land-drain, Chitcombe

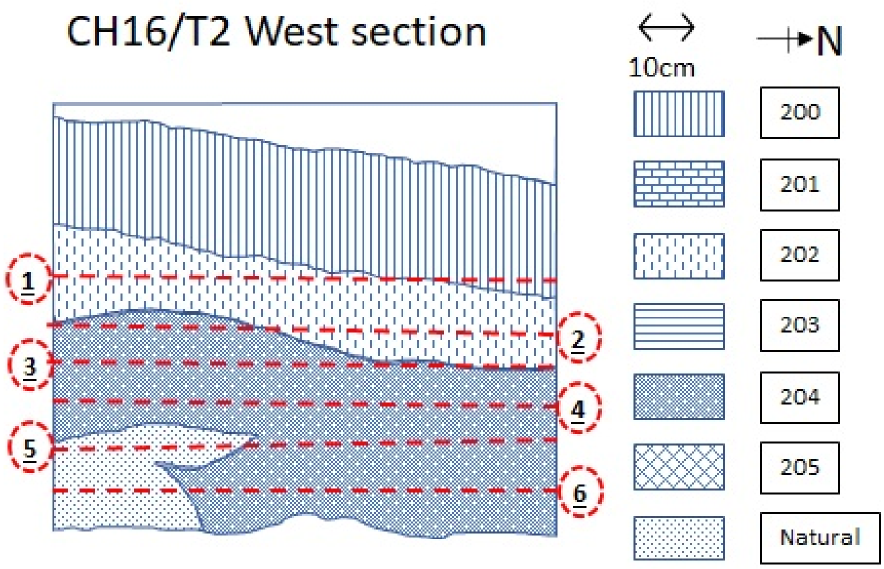


FIGURE 5.9: West section of trench 2, Chitcombe

Trench 13

Trench 13 (fig5.10) measured 1x1m and had a maximum depth of 0.60m, giving a volume of 0.6m^3. Within this trench there were two contexts (1301, and 1302), and it was excavated in four spits (fig5.11). This trench was excavated into an area that was believed to represent part of the technological waste deposits. A full range of technological waste was discovered in this trench. The total weight of material removed from T13 was 689.90kg consisting of 589.60kg of matrix and 100.30kg of technological waste (ap B.32).

FIGURE 5.10: Section with spit lines of T13, Chitcombe

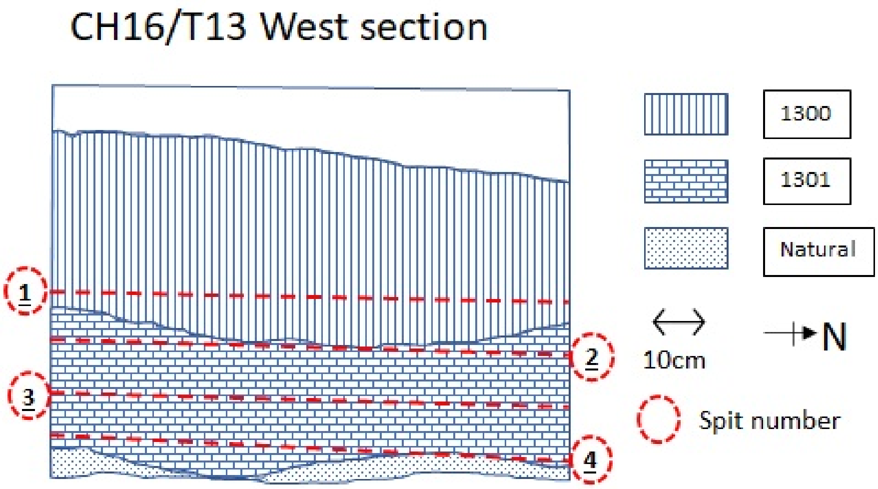


FIGURE 5.11: West section of trench 13, Chitcombe

Trench 14

Trench 14 (fig5.12) measured 1x1m and had a maximum depth of 1.90m giving a volume of 1.9m^3. Within this trench there were six contexts (1401, 1402, 1403, 1404, 1405, 1406), and was excavated in 15 spits (fig5.13). This trench was excavated into an area that was believed to represent part of the technological waste deposits. A full range of technological waste was discovered in this trench. The total weight of material removed from T14 was 2017.80kg consisting of 622.6kg of matrix and 1395.20kg of technological waste (ap B.32). This trench was excavated in two stages, the first in the summer of 2016 and the second in the autumn of 2016. Due to this there was a notation change between the spits to be able to identify in which season which were excavated. In the summer excavation numbers were used (spits 1-7) and in the autumn excavation letters (spits A-E).

Due to the depth and form of undisturbed deposits it was decided that T14 would be the focus of analysis as trenches 1, 2, and 13 were deemed to be not in the undisturbed waste deposits and therefore would not answer this project's aims. From all the trenches excavated to quantify the waste deposits it was decided that only T14 represented samples from the undisturbed waste deposits. For the purpose of this project, and time constraints, it was decided that an appropriate dataset could be collected by analysing alternate spits. Therefore, spits 1, 3, 5, 7, A, C, E were used for analysis.

FIGURE 5.12: View of extended T14, Chitcombe

5.3.2 Quantification of technological waste from Trench 14

The material collected during excavation can be quantified in a number of different ways. This includes by size category and by material type. This is all set out in Appendix B.3. A number of these tables will be used here to discuss them in depth so that all the tables can be understood.

The first to be discussed will be the total material by spit (Tab.5.1). The first three headings in this table are self explanatory with site code, trench number and spit number.

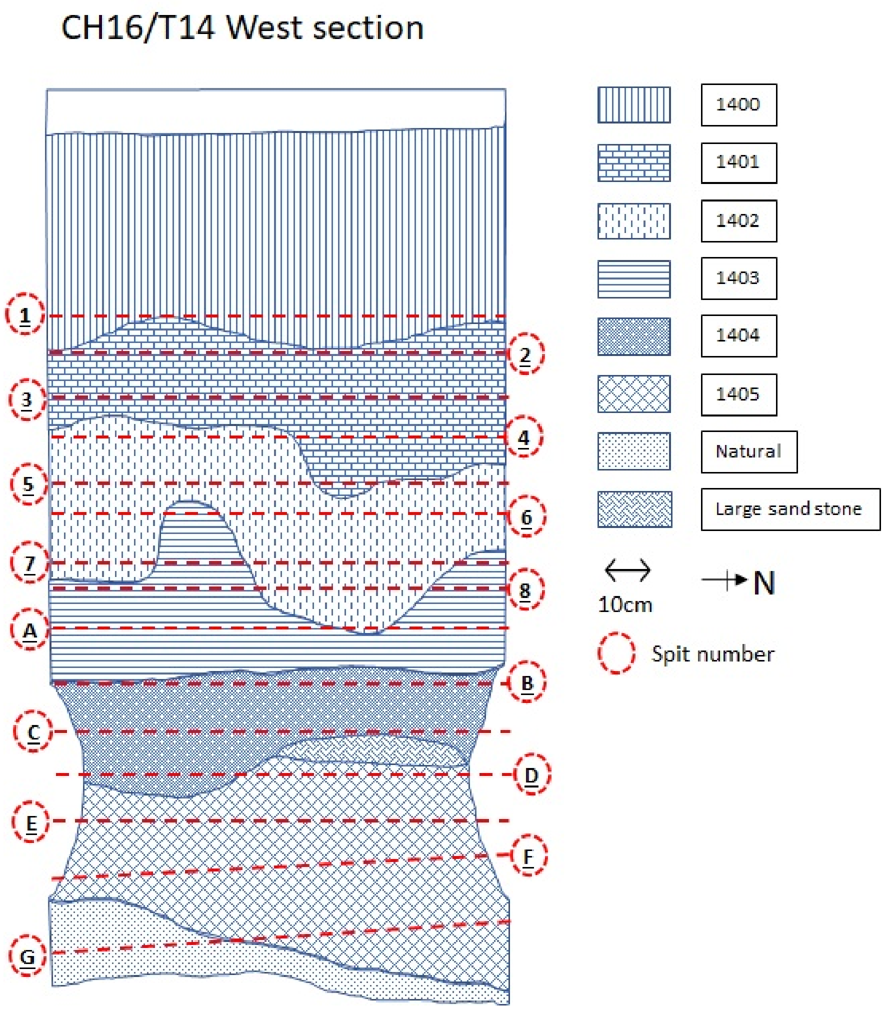


FIGURE 5.13: West section of trench 14, Chitcombe

The 'spit weight' category gives the total weight of all the material from the spit. Despite the spits being near-uniform in dimensions the data shows considerate variation in spit weights, ranging from 82.60kg to 142.90kg, a difference of 60.30kg. A difference is expected as the formation of the spits is not homogeneous. If a spit has more dense slag and less fine residue, or less dense furnace material, it would be heavier than those with more matrix. This can be more clearly seen in the graph in figure 5.14 where all materials can be seen fluctuating across spits.

TABLE 5.1: Total material by spit

Total material by spit (kg)						
Spit	spit weight	slag	FM	Geo	FR	total
1	96.10	26.24	1.69	2.96	65.11	96.00
3	131.80	56.21	7.69	4.41	63.49	131.80
5	129.30	40.21	12.04	5.83	71.22	129.30
7	132.30	80.60	3.74	2.49	45.47	132.30
A	142.90	96.18	1.26	5.54	39.92	142.90
C	94.75	43.89	2.43	2.57	45.86	94.75
E	82.60	28.21	9.63	7.12	37.63	82.60
total (kg)	809.75	371.55	38.48	30.92	368.70	809.65

The next four column headings denote the material (slag, furnace material, geological material, and fine residue) identified. Slag is defined as any sample that was fully or primarily formed of Slag. Furnace material (FM) is defined as any material formed of fired clay or vitrified clay. Geological is defined as any stone material, this includes, but not limited to, sandstone, and raw or roasted iron ore. The fine residue is the remaining weight of the spit and is defined by material below 50μ.

When looking at the total constituent weights of these spits it can be seen that there is 371.55kg of slag, 38.48kg of furnace material, 30.92kg of geological material, and 368.70kg of fine residue. As % this translates into 45.9% slag, 3.9% furnace material, 3.2% geological material, and 47.0% soil matrix.

Quantification of sub-samples from Trench 14

Due to time constraints in this project and the time taken to process and classify the mixed small and mixed matrix material, it was decided to analyse a

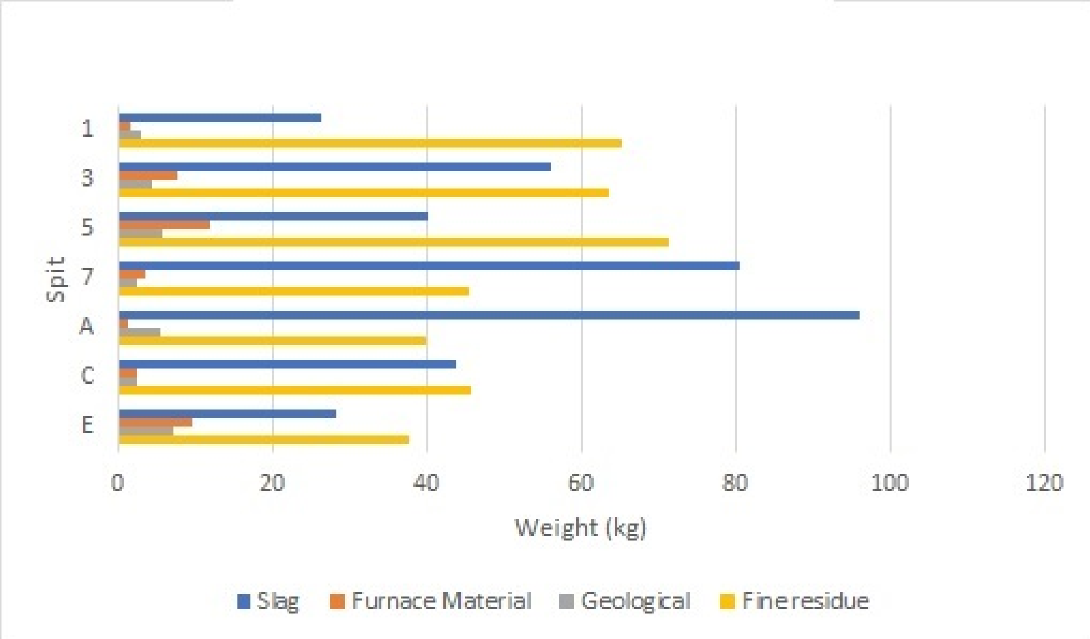


FIGURE 5.14: Total weight of materials by spit (kg)

1kg sub-sample from each. The raw data was then extrapolated from the sub-sample to calculate the representation in the whole spit. Two tables have been created for each material as can be seen in AppendixB.3.5. The matrix category will be discussed here for a clearer understanding (AppendixB.3.4).

TABLE 5.2: Chitcombe Trench 14 - Quantification of 1kg sample of mixed matrix by spit level (kg)

Spit	MMa	matrix	Slag	FM	Geo	FR	total
1	1.000	0.050	0.015	0.005	0.030	0.950	1.000
3	1.000	0.075	0.021	0.006	0.048	0.925	1.000
5	1.000	0.100	0.030	0.009	0.061	0.900	1.000
7	1.000	0.050	0.018	0.005	0.027	0.950	1.000
A	1.000	0.150	0.065	0.014	0.071	0.850	1.000
C	1.000	0.200	0.148	0.011	0.041	0.800	1.000
E	1.000	0.200	0.064	0.024	0.112	0.800	1.000
total	7.000	0.825	0.361	0.074	0.390	6.175	7.000

The first table (tab.5.2) sets out the weights calculated from the 1kg sub-sample by spit. The mixed matrix (MMa) is the 1kg sub-sample which consists of material below 6mm. This is washed through the 50μ mesh which separates into 'matrix', material <6mm>50μ, and fine residue (FR), material <50μ. The matrix is then sorted into the material categories, slag, furnace material (FM), and geological material (geo).

TABLE 5.3: Chitcombe Trench 14 - Quantification of extrapolated mixed matrix by spit level (Kg)

Spit	MMa	matrix	slag	FM	Geo	FR	total
1	68.54	3.43	1.03	0.34	2.06	65.11	68.54
3	68.64	5.15	1.44	0.41	3.29	63.49	68.64
5	79.14	7.91	2.37	0.71	4.83	71.22	79.14
7	47.86	2.39	0.86	0.24	1.29	45.47	47.86
A	46.96	7.04	3.05	0.66	3.33	39.92	46.96
C	57.32	11.46	8.48	0.63	2.35	45.86	57.32
E	47.04	9.41	3.01	1.13	5.27	37.63	47.04
total (kg)	415.50	46.80	20.25	4.12	22.42	368.70	415.50

The second table (tab.5.3) sets out the extrapolated data for the matrix samples obtained from the 1kg sub-sample. The mixed matrix (MMa) column in this table shows the complete weight of this category by spit calculated from MMa weighed during excavations and that lost from washing the large and small. This known weight is used as the basis for the extrapolation using the equation $X(\frac{Y}{1000})$, where X is the weight of the material from the sub sample and Y is the complete MMa weight. If the slag from spit 1 is used as an example the extrapolated weight is $15(\frac{68540}{1000}) = 1028$. This was completed for all slag, FM, geo, and FR weights from the sub-sample to give the data in table 5.3.

Due to the change in method in material collection the true value of the small slag, FM, and geo is known for spit 1-7. Spit A-E has been treated in the same way as the matrix, with a 1kg sub-sample of mixed small (MSm) being washed to give a small weight, which when separated gives slag, FM, geo, and FR (tab.B.34). These are then extrapolated using the same equation as the matrix (tab.B.35).

5.3.3 Classification and typologies of Trench 14

A total of 3014 individual samples were classified from T14, forming 38 different types within the broad categories of slag, furnace material and geological material (fig 5.4, ap B.5).

TABLE 5.4: Number of samples, types and dominant types across the spits in T14

Spits	1	3	5	7	A	C	E
no. of samples	238	444	402	752	574	314	290
no. of types	16	21	16	14	12	9	8
no. of dominant types	10	9	8	10	7	7	6

How the material was classified is set out in detail in chapter 3. The large material was assessed per spit with all material being sorted into types according to morphology. The types were then classified with data being recorded on each including, but not limited to, weight, morphology, porosity, and inclusions. This was repeated for the large material from each spit.

To meet the aims of this project only dominant types will be looked at for analysis. A dominant type is one that is present in more than half of the quantified spits (tab.5.5) and represents the consistency of the technology and optimum operation. By looking at these dominant types changes in the normal processes and parameters can be seen.

TABLE 5.5: Presence of dominate types in analysed spits of T14

Types	1	3	5	7	A	C	E	total spits
Baked Clay	Y	Y	Y	Y	Y	Y	Y	7
corrugated	Y	Y	Y	Y	Y	Y	Y	7
FMT	Y	Y	Y	Y	Y	Y	Y	7
Fractured	Y	Y	Y	Y	Y	Y	Y	7
Smooth	Y	Y	Y	Y	Y	Y	Y	7
Flat	Y	Y	N	Y	Y	Y	N	5
Rough surface	Y	Y	Y	Y	Y	N	N	5
Grompy	Y	N	N	Y	N	Y	Y	4
Vitrified	Y	Y	Y	Y	N	N	N	4
Furnace	Y	Y	Y	Y	N	N	N	4

Abbrev.Y=present.N=absent

Of these dominant types (tab.5.5) there are five that are present in all seven spits. These include baked clay, corrugated, fluid movement tendril, fractured, and smooth. There are two types present in 5 spits including flat and rough surface, and three that are present in 4 spits, including furnace, grompy, and vitrified (type descriptions AP.B.4). All other types are only represented in three or less spits. These types will not be analysed in great depth as they are deemed to be atypical, produced due to a random event rather than a change in the process. Therefore, it will only be the types present in four or more spits that will be analysed in more depth unless a type is highly specific to a process or action. How these types are represented in each spit and across the trench is presented in figure 5.19 later in this chapter and will be discussed in depth then.

A number of information points were collected on each type during the classification (set out in chapter 3). In appendix B.5 the most abundant three dominant types by weight have been tabulated with their classification information. Across spits 1, 3, 5, A, and E the most abundant three types by weight are dominant types. In spit 7 the third abundant type by weight, and in spit C the first, are non-dominant types. This shows that the non-dominant types can be highly representative in a spit. The data from spit 5 will be used here as an example so all other classification data can be better understood (tab.5.6).

TABLE 5.6: Classification of 3 most abundant dominant types by weight, Spit 5

Type	FMT	corrugated	Vitrified
Material	slag	slag	FM
Weight(g)	11500	7900	4600
Number	113	105	40
Min/max size	3.4x2.2 / 10.6x7	2.8x2.5 /9.2x6	3.5x2/11x8
Shape	amorphous	amorphous	amorphous
Fracture	3-5	3-5	5-6
Porosity shape	mix	spherical	NA
Porosity size (mm)	1-8	1-27	NA
Porosity %	<10	<10	NA
Inclusions	FM/ore	FM/ore	none
Vitrification	NA	NA	complete

FMT = fluid movement tendril

Table 5.6 is set up with the classification categories down the left hand column. In the case of Spit 5 the most abundant three dominant types by weight are FMT, corrugated and vitrified. The next category sets out their material type. The weight, in grams, was measured at the time of classification with the samples clean and dry. As can be seen the difference in weight between the most represented and the least is 6.9kg, a decrease of 60%. This shows the large difference in weight that can occur over the highest three represented. This is repeated in the number of samples with FMT having 113 individual pieces and Vitrified having 40.

The minimum and maximum size category shows that there is not a large variation in the size of the samples. This could be of interest showing a breaking of the material to a more manageable size or the natural fracture size of the specific material. The shape recorded across all these types was 'amorphous'. This was common throughout the trench as samples were fractured to such a size that an overall shape of the intact artefact could not be estimated. The FMT and corrugated types had a lower fracture rate than the vitrified material. This would be expected as the vitrified type is more friable and likely to fracture and is evident through the material as a whole and not a distinguishing surface feature.

Porosity was classified using three different categories shape, size and abundance and expressed as percentage of sample volume. These attributes are not applicable for the vitrified type as the clay does not form porosity in the same sense as is formed in the liquid slag. It can be seen that between the FMT and corrugated, the abundance is the same but the size varies by as much as a factor of 3.

The inclusions category shows the vitrified has no inclusions. The FMT and corrugated both contain furnace material and ore. The inclusions can be of interest as they reflect possible working processes. An example is the ore inclusions which were found in increased quantities on the base of the samples, possibly showing the material is flowing onto a bed of this material. The vitrification of the FMT and corrugated is recorded as NA as there is no vitrified material present, as would be expected. The vitrified is complete as this group consisted of samples that were completely vitrified to varying degrees.

5.4 Analysis of quantification and Classification data

This section will look to analyse the quantification and classification data set out in the first half of this chapter. The analysis will then be used to make interpretations on the processes and working practices feeding into the wider understanding of the site itself.

5.4.1 Weight of material

The weights of materials presented previously in this chapter will be analysed in this section looking at weights by size category and material type. These weights have been converted to percentage weights to standardised the data in order to investigate underlying trends. All data can be found in Appendix B.3.5.

Slag size category

Of the slag the largest component is the large size category followed by small and the matrix (Table.5.7, Fig 5.15). This distribution of the size categories would be as expected. From the classification set out previously in this chapter it has been seen that the technology being used on site is slag tapping. This technique tends to form large pieces of slag which itself is a tough material

TABLE 5.7: Percentage weight of Slag size categories by spit (kg)

Size	large		small		matrix		
Spit	weight	%wt	weight	%wt	weight	%wt	total %wt
1	17.41	18.12	7.80	8.12	1.03	1.07	27.30
3	41.07	31.16	13.70	10.39	1.44	1.09	42.65
5	33.14	25.63	4.70	3.63	2.37	1.84	31.10
7	57.99	43.83	21.75	16.44	0.86	0.65	60.92
A	74.27	51.97	18.86	13.20	3.05	2.14	67.31
C	22.36	23.60	13.05	13.77	8.48	8.95	46.32
E	15.82	19.15	9.38	11.36	3.01	3.64	34.16
total weight	262.06	NA	89.24	NA	20.25	NA	NA

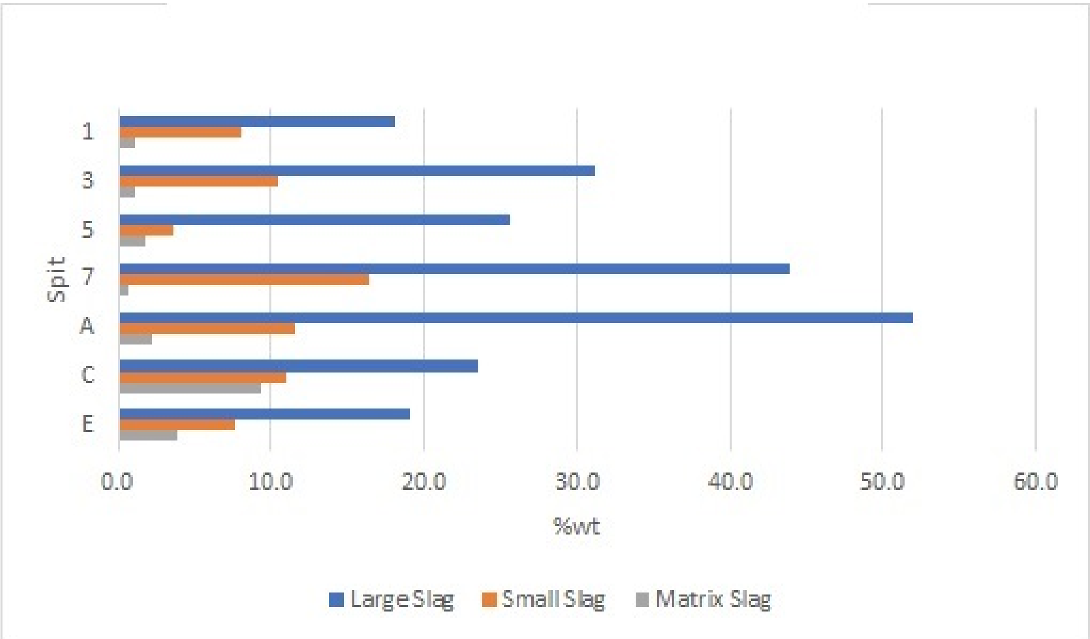


FIGURE 5.15: Percentage weight (%wt) of spit of Slag size categories, Chitcombe

that is not prone to large scale post depositional deterioration. Due to this the slag on site is likely to exist in abundance. All three of the size categories show wave-like trends of increases and decreases across the spits and therefore with depth.

The trends in the large and small categories correspond in spits 1 to 7 and A to E with the only opposing trend between spits 7 to A. This indicates an association between the occurrence of large and small slag, which is most likely due to the small slag being formed when the large slag breaks during deposition. The opposing trend between 7 and A could be down to the contexts that were present at this point in the trench. Spit 7 borders contexts 1402 and 1403, but mostly in 1402 whereas spit A is mostly in context 1403 which consisted of large slag with lots of voids. This would give the small slag space to drop through the context and settle lower down.

The trends of the matrix category are opposed to those of the large and small category the majority of the time. The reason for this is unclear. It could be that the matrix category is being formed in a different process to the large and small categories. It could also be misrepresented in the spits as it has been moved through bioturbation.

Furnace material

TABLE 5.8: Percentage weight of furnace material size categories by spit (kg)

Size	large		small		matrix		
Spit	weight	%wt	weight	%wt	weight	%wt	total %wt
1	0.85	0.88	0.50	0.52	0.34	0.36	1.76
3	5.88	4.46	1.40	1.06	0.41	0.31	5.83
5	6.53	5.05	4.80	3.71	0.71	0.55	9.31
7	1.95	1.47	1.55	1.17	0.24	0.18	2.83
A	0.31	0.22	0.30	0.21	0.66	0.46	0.88
C	1.38	1.46	0.42	0.44	0.63	0.67	2.57
E	6.00	7.26	2.51	3.03	1.13	1.37	11.66
total weight	22.89	NA	11.47	NA	4.12	NA	NA

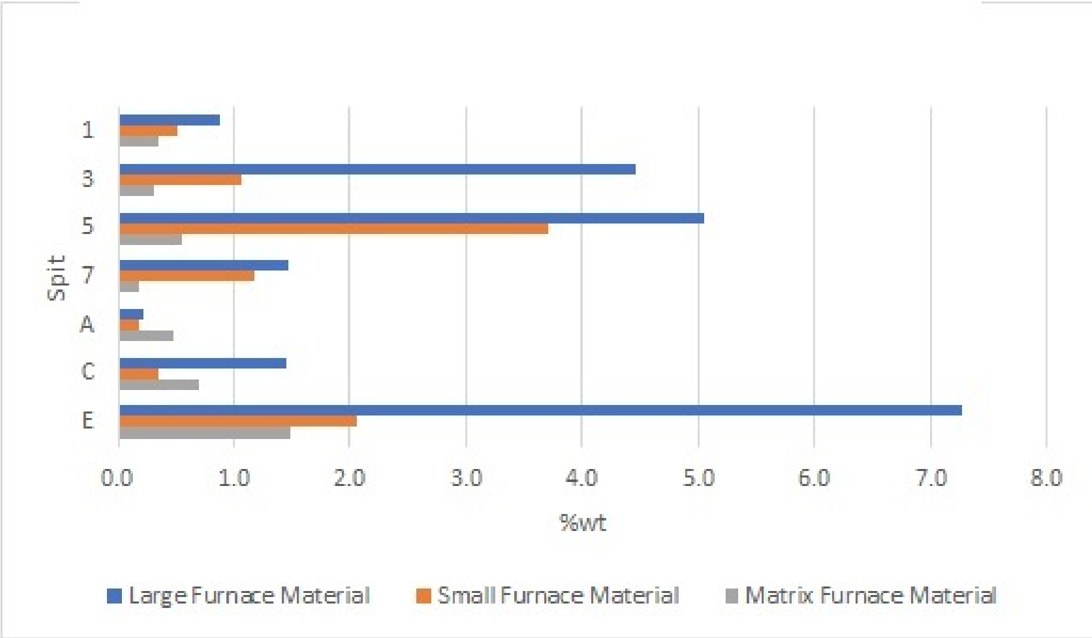


FIGURE 5.16: Percentage weight (%wt) of spit of furnace material size categories, Chitcombe

Of the furnace material (Table 5.8, Figure 5.16) the largest component is the large size category with the exception of spit A where the matrix size category is the most abundant. The small size category has the next highest representation with the exception of spits A and C where the matrix is most abundant. The matrix size category is the lowest across spits 1 to 7 and E, being the highest in spit A and the second highest in C. The order of representation of these size categories might be expected as the large material tends to be well burnt or vitrified material and has better structural integrity and survives in larger pieces. The small and matrix can be explained by fracturing and breaking of the furnace material during repair of the furnace or deposition. Moreover, it must be noted that these size categories could have been increased in representation by the sieving method used to separate the size categories. The decrease in the large and small categories in Spit A can be explained by context 1403 which was formed of large amounts of slag with voids.

All three of the furnace material size categories show wave trends with the large and small categories being the most obvious (Table 5.8, Figure 5.16). These size categories increase from spit 1 to 5, decrease to A, then increase again to E. This sharp increasing and decreasing could represent phases of smelting and furnace repair/rebuild. However care must be taken with this interpretation due to the processes of deposition which will be discussed in more detail in Chapter 10. The correlation of trends shows a direct association between the large and small categories, most likely due to the small being produced by fracturing of the large material in a standard pattern.

Geological material

TABLE 5.9: Percentage weight of geological size categories by spit (kg)

Size	large		small		matrix		
Spit	weight	%wt	weight	%wt	weight	%wt	total %wt
1	0.00	0.00	0.90	0.94	2.06	2.14	3.08
3	0.02	0.01	1.10	0.83	3.30	2.50	3.35
5	0.00	0.00	1.00	0.77	4.83	3.73	4.51
7	0.00	0.00	1.20	0.91	1.29	0.98	1.88
A	1.91	1.34	0.30	0.21	3.33	2.33	3.88
C	0.00	0.00	0.22	0.24	2.35	2.48	2.72
E	0.95	1.15	0.91	1.10	5.27	6.38	8.62
total weight	2.88	NA	5.62	NA	22.42	NA	NA

Of the geological material (Table 5.9, Figure 5.17) the most abundant across all spits is the matrix size category. The next is the small category which is the second most represented across spits 1 to 7 as well as C, being the least

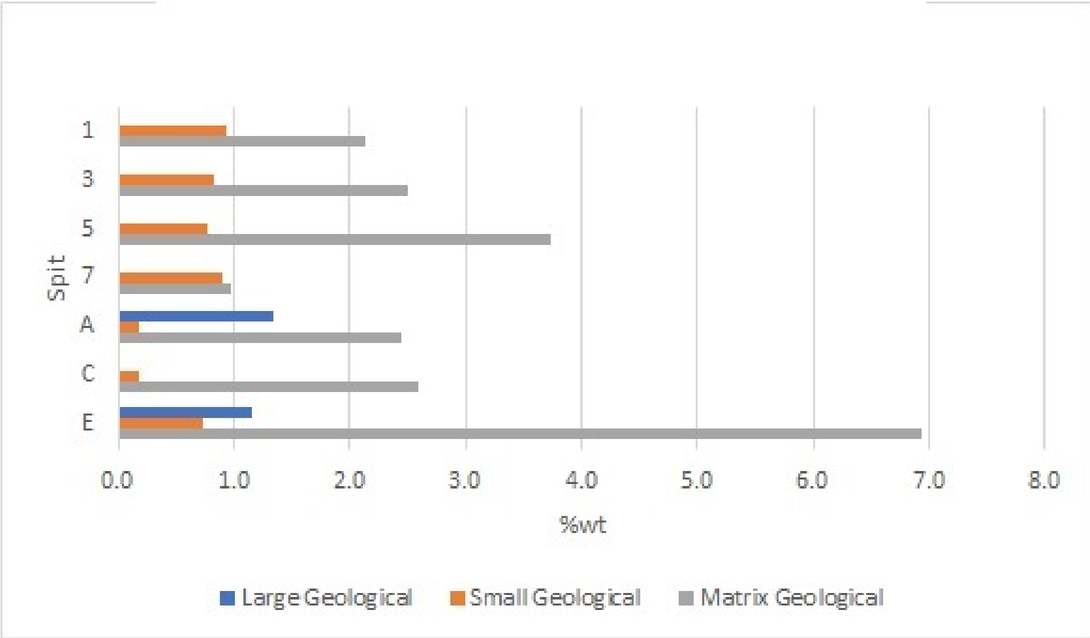


FIGURE 5.17: Percentage weight (%wt) of spit of geological size categories, Chitcombe

represented in spits A and E. Finally large is the least represented across spits 1 to 7 and C, being the second most represented in A and E. The majority of geological material in the matrix size category consisted of roasted ore fines. This could then show that ore was being sorted off site, with only viable ore being brought onto the site to be roasted and sorted.

The pattern of occurrence of the geological material is reversed compared with the slag and furnace material, which is a point of interest. This is not believed to be due to larger geological material being broken during or after deposition, but is rather the true reflection of the nature of the material. It is also not believed that the method of sieving has created smaller and matrix categories as the geological material is stable enough to withstand the mechanical movement of sieving. This then shows a process occurring elsewhere, either on or off site, is producing geological material between 50μ to 6mm in increased quantities. It is most likely from the crushing and processing of ore.

The large size category is not present in spits 1 to 7 as well as C (Table 5.9, Fig 5.17). No trends can therefore be inferred from the data and with such a low occurrence it can be regarded as statistically insignificant, most likely reflecting random inclusions. An interpretation could be that geological material is not being wasted on site which would imply a level of sorting of ore or structural material off site.

The small category is stable across spits 1 to 7 only fluctuating by 0.1%wt (Table 5.9, Fig 5.17). It then decreases across A and and C before increasing to E. The decrease at A and C is most likely due to the contexts at these position, 1403 which contains a large amount of slag and voids and 1404 which also consists of a large amount of slag and fine residue. With no values for this size category above 1%wt it can be seen as a fairly stable trend once Spit A is removed as an outlier. This could be interpreted as not being associated with any particular process or a process that is occurring continuously and simultaneously with the smelting.

The matrix size category shows a wave trend, increasing from spit 1 to 5, decreasing to 7, and then increasing to E (Table 5.9, Fig 5.17). The increase to E being particularly sharp and high. This wave trend suggests a cyclical process likely to be ore fines either associated with the processing of the ore or cleaning out of the furnace.

All materials

TABLE 5.10: Percentage weight of materials by spit (kg)

Size	FR		slag		fm		geo		
Spit	weight	%wt	weight	%wt	weight	%wt	weight	%wt	T %wt
1	65.11	67.76	26.24	27.30	1.69	1.76	2.96	3.08	100
3	63.49	48.17	56.21	42.65	7.69	5.83	4.41	3.35	100
5	71.22	55.08	40.21	31.10	12.04	9.31	5.83	4.51	100
7	45.47	34.37	80.60	60.92	3.74	2.83	2.49	1.88	100
A	39.92	27.93	96.18	67.31	1.26	0.88	5.54	3.88	100
C	45.86	48.40	43.89	46.32	2.43	2.57	2.57	2.72	100
E	37.63	46.95	28.21	45.93	9.63	3.86	7.12	3.23	100
TW	368.70	NA	371.55	NA	38.48	NA	30.92	NA	NA

TW = total weight of material, T%wt = total percentage weight per spit

By comparing the trends of increase and decrease it is possible to associate materials with patterns which could imply activities, production and deposition. Of all nine material and size categories there is only one pair that match in their pattern of fluctuations and that is the large and small furnace material. This would make sense as the furnace material is friable and fragile, and prone to breakage, creating the small size from the larger. The large and small slag categories match in trends for six out of seven spits. This probably has the same interpretation as the furnace material, with the small being created when the large is broken during deposition. The slag in the matrix category and the small geological material directly oppose each other in their fluctuations. It is difficult to pinpoint reasons, and could simply be down to correlation not causation. When looking at the data it can be seen that the slag from the matrix category has a much larger variance whereas the small geological material is more stable. This suggests that the inverted correlation most likely has no causation.

To understand further any trends in the material it has to be looked at by merging the size categories, therefore representing as percentage weight of the whole spit. This can be seen in Table 5.10 and Figure 5.18.

The clearest opposing trend is between the slag and fine residue. This may be simply explained as statistical, as together they dominate the record and there will be an inverse relationship, with the furnace material and geological being very low in occurrence. The fluctuations in slag could be indicative of periods of more and less smelting intensity, or the organisation of processes such as smelting and the repairing or renewing the furnace.

The idea is widely accepted that technological waste deposits on iron production sites will be formed in repetitive bands split by increased slag and increased furnace material. If this is the case then it would be expected to be seen in the data that when the amount of one increases the other decreases and vice versa. When comparing the data here it can be seen that the slag and furnace material do alternate with each other from spit 3 through to spit E, showing that less slag is associated with increased furnace material and a potential cyclical process. From spit 3 through to spit E the geological material alternates between increasing and decreasing. This also gives the impression of cyclical working and deposition.

To further understand the trends in representation of material and the interpretation of the trends (fig.5.18) the spits need to be compared in greater depth to the contexts they exist in (fig.5.13).

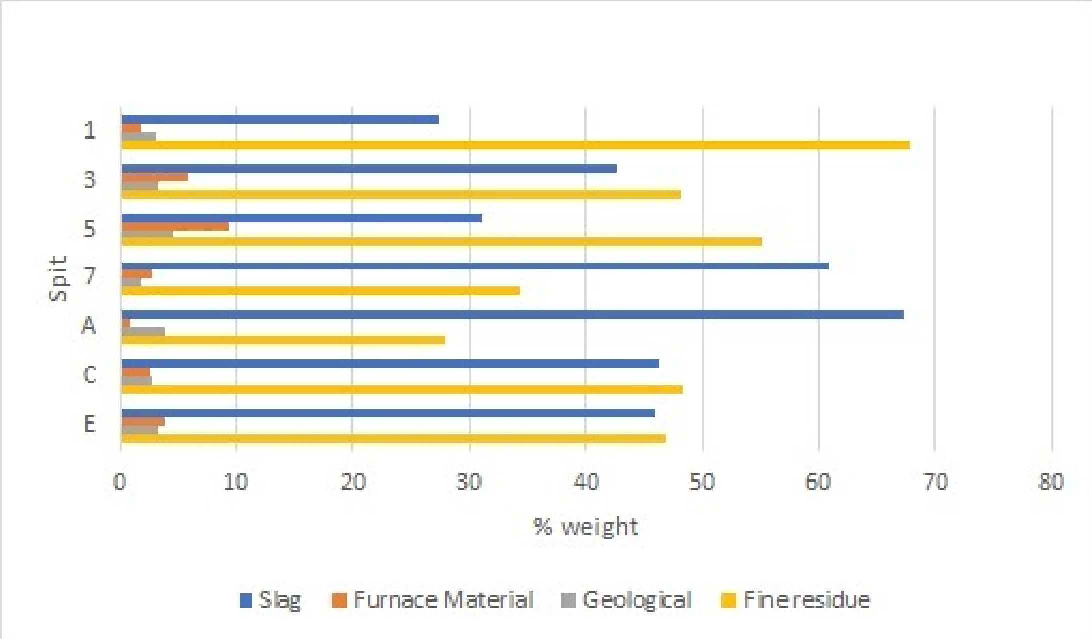


FIGURE 5.18: All material as percentage weight of spit, Chitcombe T14

Spit 1 exists predominantly in context 1401 which looks very similar to the topsoil but has a markedly higher visibility of slag. However there are also small section of spit 1 that are in context 1400 which is the top soil. Within this depth of the ground there is a higher change of bioturbation through ploughing or animal and insect action. This could be one of the possible explanations for the increased proportion of fine residue in this spit.

Spit 3 crosses context 1401 and 1402. Context 1402 was noted as having a higher visibility of furnace material in it compared to 1401 even-though the general matrix was very similar looking being light yellow/brown clay rich soil. This visible change in the furnace material can be seen by an increase in representation from spit 1 but lower than spit 5.

Spit 5 is positioned within context 1402 with a higher representation of furnace material than spit 3. It also has a smaller representation of slag than spit 3. This could show the possible influence from context 1401, which has visibly higher slag, or it could show that even within a spit there is high variation.

Spit 7 and A both show a dominance in the amount of slag over fine residue. Both these spits are being influenced by context 1403 which was formed of large amounts of slag surrounded by voids.

Spits C and E both have very similar representations of all materials even though spit C is represented by context 1404, which is defined as compact slag with a dark brown matrix, and spit E by context 1405, which is defined as having very dark matrix like charcoal. This could show the possibility of two spits having the same representation of material by chance, or that a single deposition of similar material has been assigned two contexts.

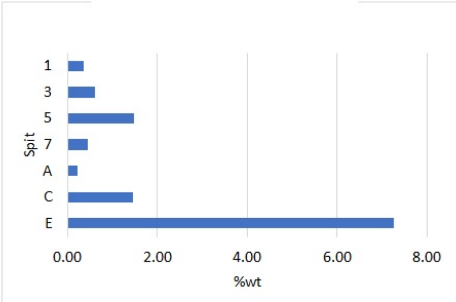
5.4.2 Classification of technological waste

As seen previously all material was classified to form a number of different types (ap B.4). The types identified as being important, dominant types, are those which occur repeatedly and are represented in over half the spits. Common occurrence is believed to reflect the standard and optimal conditions of smelting. Five types were identified that are present in all seven spits; baked clay, corrugated, fluid movement tendril, fractured, and smooth. Two types present in 5 spits including flat and rough surface, and three types that are present in 4 spits, including furnace, grompy, and vitrified.

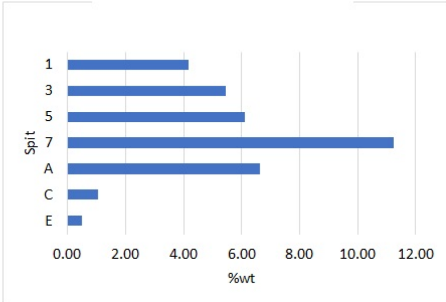
To understand the occurrence of each of these types throughout the trench they have all been turned into percentage weights and plotted on separate graphs (fig.5.19).

When comparing the trends it can be seen that all these types are represented throughout the trench in very different ways. There are only two types that have a highly similar trend. These are the rough surface (fig 5.19g) and the furnace (fig 5.19i) types. These two types of slag have the same trends apart from between spits A and C where the rough surface has a small decrease and the furnace stays at 0%wt. Due to so many dis-similarities in exact trend patterns a broader look has to be taken at general trends.

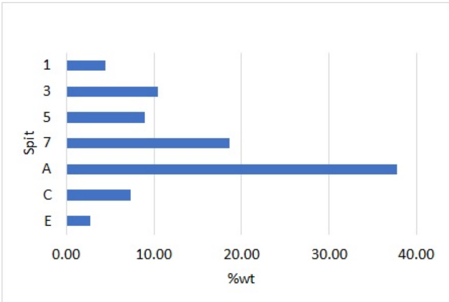
Six of the types; corrugated (fig 5.19b), smooth (fig 5.19e), flat (fig 5.19f), rough surface (fig 5.19g), vitrified (fig 5.19h), and furnace (fig 5.19i) all decrease from spit 7 to spit E. If this is shifted slightly to decrease from A to E then fluid movement tendrils (fig 5.19c) can also be added to this group. The remaining types then oppose this trend with fractured increasing from spit 7 to E, and baked clay (fig 5.19a) and grompy (fig 5.19j) increasing from spit A to E. With a decrease in many types of slag and a large increase in baked clay (fig 5.19a), which is representative of the furnace material, a change can potentially be seen in the lower levels of the trench which could indicate a process of increased smelting and furnace rebuilding from spits 7 to E. Spits 1 to 7 seem to be much more varied in the percentage weights of the individual types. Four of the types show similarities throughout spits 1 to 7 with an increase from spits 1 to 3, decrease from spits 3 to 5 then increase from spits 5 to 7. The fractured and flat types also show potential similarities with a decrease from spits 1 to 3 before an increase from spit 5 to 7.



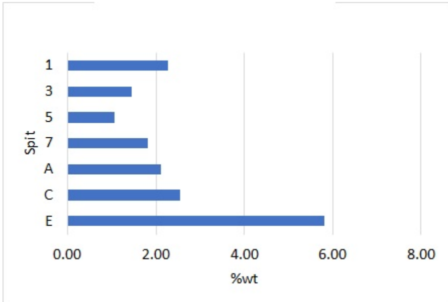
(A) %wt of Baked Clay, Chitcombe



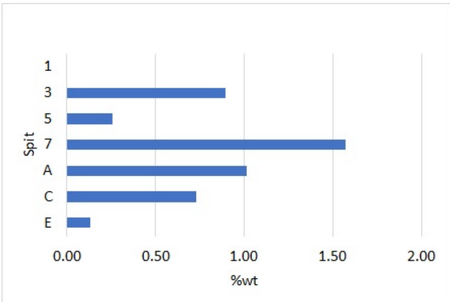
(B) %wt of Corrugated, Chitcombe



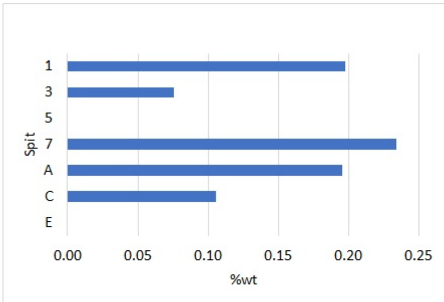
(C) %wt of Fluid Movement Tendril, Chitcombe



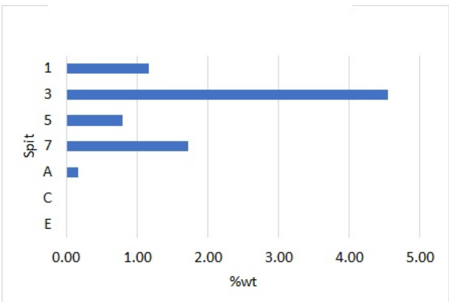
(D) %wt of Fractured, Chitcombe



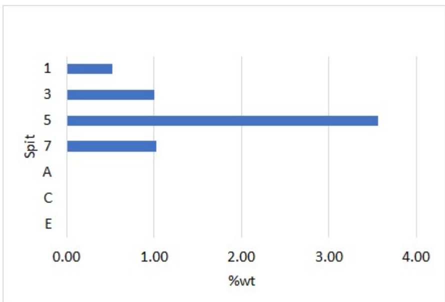
(E) %wt of Smooth, Chitcombe



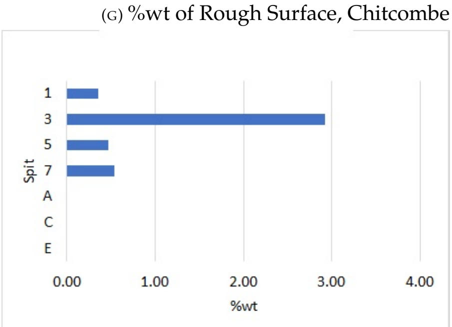
(F) %wt of Flat, Chitcombe



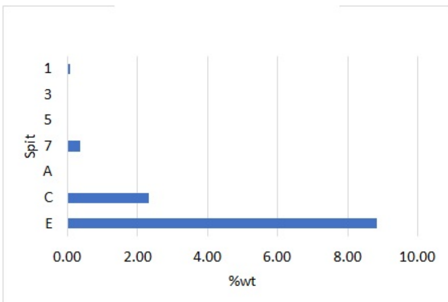
(G) %wt of Rough Surface, Chitcombe



(H) %wt of Vitrified, Chitcombe



(I) %wt of Furnace Slag, Chitcombe



(J) %wt of Grompy, Chitcombe

FIGURE 5.19: Graphs depicting % weight of individual types of the initial spit weight, Chitcombe T14

Care must be taken when looking at these trends as the intensity of the increases and decreases can differ greatly meaning a match in trends may not necessarily mean an association in the formation of these types.

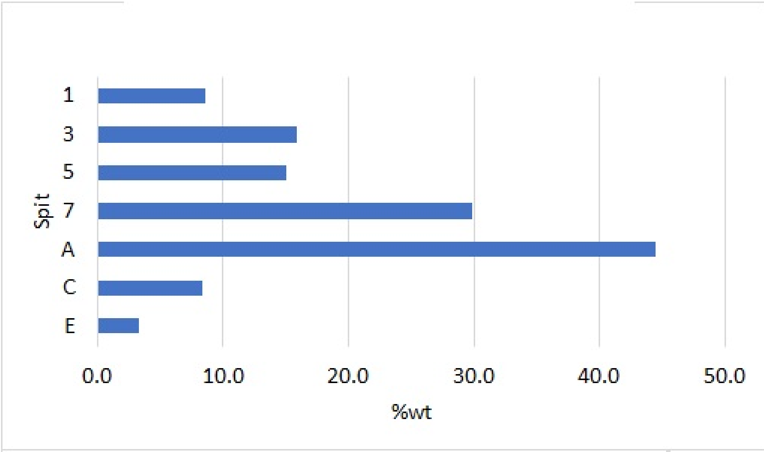
Many of the types described can potentially be ascribed to a specific action or point in the smelting process. An example of this includes the fluid movement tendril type which represents slag tapping with the fluid slag running out of the furnace before solidifying, creating a ropey worm-like texture of flowing tendrils. This type can then be ascribed to this process, meaning an increase or decrease in this type of material may indicate an increase or decrease in slag tapping. Similarly, the baked clay and vitrified types reflect the furnace itself and would, in the most cases, be removed from the furnace when the slag is being cleared out after the smelt or during repair or rebuilding of the furnace. This then again indicates a specific process or action that is undertaken and maybe identified looking at the increase and decrease in occurrence. However, it can be seen that the appearance of many of these types is to a degree random and incoherent as there are a number of types that are only identified in one or two of the spits. This is understandable as the process as a whole is highly influenced by the ore being used, the temperature in the furnace, reducing conditions, and fluidity of slag when tapped. It is thus understandable that varying conditions will occur which produce different looking pieces of slag, not because they represent a distinct process but because they represent the variation that can occur in an otherwise optimised smelting process.

As has been seen a number of the types can be associated with a specific process that occurs during the smelting process. On occasions a number of these types derive from the same process, hence by joining them together they form larger groups which can inform more closely on the processes and actions, and potential organisation of the processes on the site.

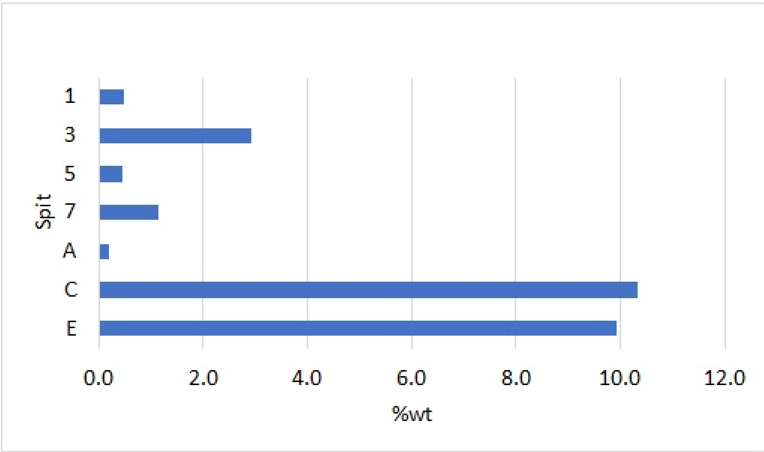
It has been seen that the technology being used on the site for smelting is 'slag tapping'. However, the slag type 'corrugated' can be used as a proxy to fluid movement along with the obvious type 'fluid movement tendril'. These two types when conjoined will give a better understanding of when the most intense periods of smelting might be occurring and have been given the group type 'Movement'. Looking at the 'Movement' graph (Fig: 5.20a) it can be seen that the occurrence of these two types, which implies tapping from the furnace, as a percentage of the whole spit, increases sharply from spit 5 to spit A before dropping sharply to spit C. This shows the period from spit 5 to spit A represents a time of intense smelting where a higher volume of slag is being removed from the furnace via tapping. When comparing this area to the contexts it can be seen to cover predominantly contexts 1402 and 1403. As has been seen context 403 contains a high percentage of slag with voids. This may show that there was a larger amount of material deposited in a short time which means there was no time for matrix to fill the lower levels of the deposit. This shows a possible high intensity and volume in the smelting process.

There are a number of types that have been identified and described which can be seen as representative of material formed within the furnace that could have only been extracted through human removal. This includes the types 'furnace', 'furnace mixture', 'furnace gromp', 'grompy', 'grompy adhesions', and 'fluid tendril furnace'. When all these types are conjoined, being given the group type name In Furnace, and shown on a graph as a percentage weight of the entire spit (Fig: 5.20b), it can be seen that there is a small increase at spit 3 which cannot be explained by the contexts as this is being influenced by contexts 1401 and 1402 (fig 5.13). The major trend in this data is the large increase in material in spit C and E. This represents contexts 1404 and 1405, both of which have a very dark colouration to their matrix and visible charcoal in 1405 which matched the slag interpretation as coming from inside the furnace. This shows a major period of furnace clearance. When this is compared with the graph of movement slag group representing tapping it can be seen that at this point the In Furnace group decreases. This shows an obvious process of clearance of the furnace and smelting.

There are a number of types formed of furnace materials including 'Baked Clay', 'Vitrified', and 'Furnace lining'. Only three pieces of 'furnace lining' were identified, one in spit 3 and two in spit 5. Rather than group the baked clay and vitrified types they have been kept separate. The reason these have been kept separate is they may represent slightly different processes. The more vitrified material may represent smaller scale re-lining of the furnace, as this is the part of the furnace where a high level of vitrification could occur, whereas the baked clay may represent a more intense repairing or rebuilding of the furnace as this material comes from deeper within the structure of the furnace. As has been described appendix B.4 the baked clay does include a certain amount of vitrified material but has a higher proportions of baked clay and non-glassy vitrification. When the baked clay is plotted on the graph (Fig: 5.19a) it can be



(A) %wt of spit of Movement category, Chitcombe



(B) %wt of spit of In Furnace category, Chitcombe

FIGURE 5.20: Graphs depicting group categories as percentage weight of the spit, Chitcombe

seen that there is a slight increase at spit 5. There is then an increased representation in spit C, context 1404, with spit E being the dominant representation, context 1405. When looking at the vitrified material (Fig: 5.19h) there is a slight increase in spit 3 before a sharp increase in spit 5. The percentage weight then decreases in 7 and then is not represented in spit A, C, or E. Taking all this information into account, including the pieces of furnace lining, it can be seen that there is a spike of vitrified material and furnace lining at spit 5, context

1402, with a small increase in baked clay. Whereas the large increase in the baked clay occurs in spit C and E where there is no vitrified furnace material or furnace lining. Taking into account the slag that is representative of material removed from the furnace through human action we can see that the spike at spit 3 of the in-furnace group is represented by context 1402, the same as the increase in furnace lining, vitrified material and a slight increase in burnt clay. The large increase in in-furnace material from in spit C and E matches the increase in baked clay. This then suggests a picture of a small clean out of the furnace and minor repair and relining around across spits 3 and 5, context 1402, and then a mass cleaning and major repair work to the furnace across spit C and E, context 1404 and 1405.

5.5 Discussion

This section will discuss all the data presented throughout this chapter putting it in context with reference to the site. A discussion will then be had placing Chitcombe into a landscape setting.

5.5.1 Excavation

All four trenches excavated along with the geophysical surveys in 2016 were based in the north east area of field 2, as it was believed this area represented the waste deposits. Trench 1 and 13 had shallow deposits consisting of a single context of mixed technological waste. When this is combined with in-depth analysis of the magnetometer survey and understanding of other trenches excavated, trench 1 and 13 have been interpreted as made surfaces, using technological waste, surrounding potential structures. The likely reason for this is to counteract the sticky wet clay in the winter. The technological waste then has a specific use here rather than being the technological waste deposit where it has been knowingly discarded.

Trench 2 contains a number of different contexts which seem to represent redeposited clay, along with the single context of mixed technological waste. A large amount of clay is used on an iron production site for the construction of smelting apparatus, such as furnaces. This large amount of redeposited clay could indicate that clay preparation was occurring near this area. Trench 2 is also bisected by a Victorian land-drain which enters the trench in the south-west corner and exits in the northern end of the eastern section. This means that the trench as a whole has been disturbed and the finds of pottery within the trench are not stratified and cannot be trusted to represent layers or even the trench as a whole as they could have been inserted from elsewhere when the land-drains were placed. This trench is then not believed to represent in-situ archaeological waste deposits.

Trench 14 was placed away from the initial area of investigation at the furthest extent of the Earth Resistivity Tomography/Induced Polarisation survey. This trench is believed to represent the true technological waste deposits from smelting and is believed to be undisturbed and still in-situ. The variation in contexts throughout the trench give an impression of cyclical work, with layers of increased furnace material and layers with increased slag as well as charcoal-rich contexts. All pottery discovered in this trench from contexts 1401, 1402, 1403, 1404 and 1405 dates from between AD 43-150 with the potential later pottery being in 1402. This could mean that the creation of the waste deposits was early on in the occupation of Britain by the Romans.

FIGURE 5.21: Chitcombe Trench 3 - In situ Roman tile floor

All the other trenches excavated across the site by HAARG and this project can help to interpret what might be happening in the different areas of the site (fig 5.5). Throughout the northeast corner of field 2 there seem to be a number of possible Roman structures. This is evidenced in trench 3, which revealed in-situ Roman floor tiles and mortar (fig.5.21). This is added to in trenches 15, 16 and 17 in which a beam slot was found which positions a potential wooden structure just behind the tiled floor structure. In addition, in trench 4 a large post hole was discovered. When compared to the magnetometer survey there seems to be a number of these anomalies evenly spaced which could indicate a further large structure.

All these possible buildings sit to the north of the remains of a slag metalled trackways, a well-defined both on the magnetometer survey and in trench 5. To the south of this are a number of ditch features as seen in trenches 7, 8, and 30. These ditches had no real diagnostic feature apart from the presence of Roman pottery. However, they do show that some effort went into demarcating this area and could be interpreted as a living area or further working areas.

FIGURE 5.22: Chitcombe Trench 22 - Corner of ditch forming smelting workshop in field 1

Trenches 9, 10 and 12 show that the smelting workshop area in F2 is in fact formed of a ditch (T9) with furnaces (T12) inside. T10 was placed between two furnaces where possible small postholes were discovered, which could indicate small structures around the furnaces themselves. This is again repeated in F1 in trenches 18 (furnace), 19, 22, 27, and 29 (all investigating ditches, fig5.22) and 23 (investigating a high magnetic anomaly). T18 uncovered the whole furnace allowing for a understanding of building and possible rebuilding as well as possible workings at the front of the furnace with post holes and layers of working (fig.5.23). T23 looked at a high magnetic anomaly set just to the south of the line of furnaces in the middle of the four. This showed a large post hole which contained a dense magnetic rusty deposit which could be evidence of smithing. This could therefore be a setting for an anvil base, or smithing waste could have been used to pack a large post hole for a structure. The majority of pottery discovered within the ditch dates from the mid-first to mid-second century AD with examples also dating from as early as 25BC. This matches the date range of the smelting workshop in F2.

FIGURE 5.23: Chitcombe Trench 18 - Remains of furnace in field 1

Trenches 20 and 21 investigated the magnetic anomalies to the south of the smelting workshop in field 1, which was interpreted as more working areas from the magnetometer survey. These two trenches uncovered large amounts of roasted ore, which explains the magnetic response, adding to the theory that this area housed working areas and/or storerooms for the material used for smelting.

5.5.2 Post-excavation analysis of materials

Looking at the macro-morphological analysis of technological debris it can be seen that the main technology being used on this site was slag tapping. This is because across all spits in trench 14 the most commonly represented type by number and weight is fluid movement tendrils or corrugated which is a proxy for fluid movement and hence tapping technology.

The trend for fluid movement tendril and corrugated slags being the most prevalent type can be seen in spits 1, 3, 5, 7, and A where these two types account for over 50% of analysed material by number and weight. However, in spits C and E grompy material becomes the most abundant type. This matches the change in contexts during excavation, where spits C and E coincide with contexts 404 and 405 which contain darker matrix and charcoal from within the furnace.

A common observation throughout almost all types of slag from Chitcombe was that on the bottom surfaces of the samples there are inclusions of geological/ore fines around 1mm in size. During excavation it was seen that the base of the furnace was full of a geological/ore rich fill. This same material may have then also been used to form an area for the slag to flow into making it easier to remove once cooled.

All samples showed signs of a high degree of fracture of their edges. These fractures were in the most part sharp but not modern. Some material was so fractured that it had no identifying features or only partial base recognisable due to its texture and inclusions of geological/ore material. This could show a working practice of breaking up the larger pieces of slag at the source to move to the waste deposits, or that the material has been moved multiple times increasing the chance of fracture. However, due to the sharp fractures it could be said they were probably covered fairly quickly and not disturbed until this excavation, therefore not moved multiple times.

Only three pieces of furnace lining were discovered in spit 3 and 5. The two pieces discovered in spit 5 were fully vitrified to a grey colour with flat edges making it look like it broke off at a specific interface. It also had glassy vitrified material on one side. The possible furnace lining from spit 3 is a thicker example and shows multiple bands of the same vitrified grey material, with some possible slag between bands of baked clay, showing evidence that the furnaces at Chitcombe were being repaired and relined.

When looking at the overall constituent weights of the spits of T14 analysed (fig.5.18) it can be seen that across the majority of the spits the most common material by weight is fine residue (<50μ). The only spits where slag is the most common by weight are spits 7 and A. This matches excavation data with a context containing a high percentage of voids. Overall the fine residue is the most common by weight at 47.0% compared to 45.9% slag, 3.9% furnace material, and 3.2% geological material. It can be seen that the amount of slag fluctuates as does the amount of furnace material. These fluctuations are opposed to each other, meaning when the slag is increasing the furnace material is decreasing and vice versa, potentially showing a cyclical process.

To further understand the process of smelting at Chitcombe and the intensity at which this action was being undertaken the ratio of furnace lining to slag can be investigated. With furnace lining representing 38.48kg and slag 371.55 which gives a ratio of 1 : 9.66 which when converted to a percentage gives 10.35%. The lower the percentage calculated the more intense smelting was occurring. This is because smelting and repair or renewal of the furnace are unique events that cannot occur simultaneously in the same furnace. Therefore the higher the amount of furnace material to slag shows the furnace is being broken repaired at a higher rate with less smelts occurring between. This is a number that can be easily calculated across a site, trench or spit to understand the intensity at different point in time or scale. At Chitcombe the high intensity of smelting can also be backed up by context 1403 which contains a large number of voids showing the slag must have been deposited in a short time period and in large volumes which stopped any time for matrix to build up and intermix.

5.5.3 Site interpretation

When all the survey data and excavation data is looked at together it can be seen that this is an extensive site and allows an understanding of potential issues with approaching the investigation of any iron production site. An initial metal detector survey of the site (Hodgkinson, 1988) and even a low resolution survey or misuse of a magnetometer survey using the wrong settings could cause a gross overestimation of the size of a site and the potential to miss features. Evidence of this is in the north-east of field 2. An area that was believed to represent the technological waste deposits but is not. This also leads to the danger of estimating the extent of waste deposits through the discovery of slag or the use of a probe to 'feel' for slag. Again, as has been seen in the area to the north-east of field 2. This area of the field has a covering of slag, most likely used to gravel the area to counteract the heavy Wealden clays and evidence of a number of possible buildings making it highly unlikely that this is the technological waste deposits. This is repeated throughout the site with slag being utilised for a number of reasons probably due to its hardness and ready availability. This includes trackways, graveling of areas and possible foundation packing.

There is also the issue of more modern-day influences on the site potentially moving material. An example of this can be seen in T2 where a Victorian land-drain was excavated through the site and placed on the 'natural' geology. When compared to the magnetometer survey it can be seen that a linear magnetic anomaly follows the line of this land-drain which could show that that excavation and redeposition of material causes a concentration or alignment of the magnetism giving rise to anomalies that could be mistaken. As well as this, while talking to farmers in the area, they have until relatively recently excavated slag for the use on tracks in and around the farm. This shows loss in the amount of slag from the site. However, this could have also caused it to be dropped and spread which would extend the site magnetically. Also, modern day land use and boundaries can influence the effectiveness of investigation of the site. The waste deposits extend further north from the investigation area towards the small stream. However, there is a solid fence, to keep the horses in the field, and thick trees and undergrowth beyond making access for survey and excavation difficult.

The investigation of Chitcombe has added significant knowledge to the site. The first is the confirmation of the building and trackway recorded by Rock (1879). As well as this, the organisation of the site has been set out on a much larger scale, including area of possible habitation and general use, areas for the preparation of material for smelting and a working practice of using the smelting workshops identified on this site consisting of four furnaces within a three-sided ditched enclosure open to the north facing the technological waste deposits and stream. It has also allowed for rigorous dating of the site from multiple sealed archaeological contexts which show that the site existed from around the time of the Claudian invasion of AD43, with the majority of the site being closed down by the mid-second century. The evidence of a tiled building, which is extremely rare in this part of the Weald, and the discovery of a bead which has been linked to military horse wear, combined with these early dates could point at a form of military control on this site. This will be discussed in more depth in future chapters.

The technological waste that was analysed across the depth of the waste deposits shows that a single technology dominated the smelting practices with the use of slag tapping furnaces. Analysis also show a potential cyclical working practice with fluctuations in the amount of slag and furnace material. This was evident in excavations where a context in T14 was almost pure slag with voids between the samples in-situ showing these were discarded quickly in a large amount then covered by a new deposit not allowing matrix to infill the voids. When the constituents of the waste deposits are examined, it can be seen that 45.9% of the waste deposit is formed of slag. This number can help to estimate the amount of iron produced on the site if an accurate volume can be calculated.

In conclusion, this study has shown that there is a great potential in the use of a multi-faceted approach of geophysical surveys and excavations and that without them gross misunderstandings can be made of site, particularly if they are as large and complex as Chitcombe. The project shows that there is a lot more work that needs to be done on this site to fully understand the smelting workshops and the areas around the sites associated with these. Further to this, more data collected from the waste deposits would allow for a more statistically significant understanding of the amount and types of material that form the technological waste deposit. With further analysis of this material a more in-depth understanding of the smelting process on this site can be reached.

6 Case Study 2 : Standen - Part A - Geo-prospection

6.1 Introduction

Case study 2, Standen, involved three stages of investigation. Geo-prospection of the site, excavation, and analysis of excavated material, creating a number of large and complex datasets. Due to this the case study has been divided into two chapters. This chapter, Part A, will focus on the background to the site, and present the geo-prospection surveys that were undertaken on the site. This will include the field strategies used, primary data collected, and a discussion of the data, with all supporting datasets being set out in Appendix C. These will be cross referenced throughout. The following chapter, Part B, will focus on the excavations and deposit sampling, again looking at the strategies used, primary data collected and a discussion of that data, with all supporting datasets being set out in AppendixD, and cross referenced throughout.

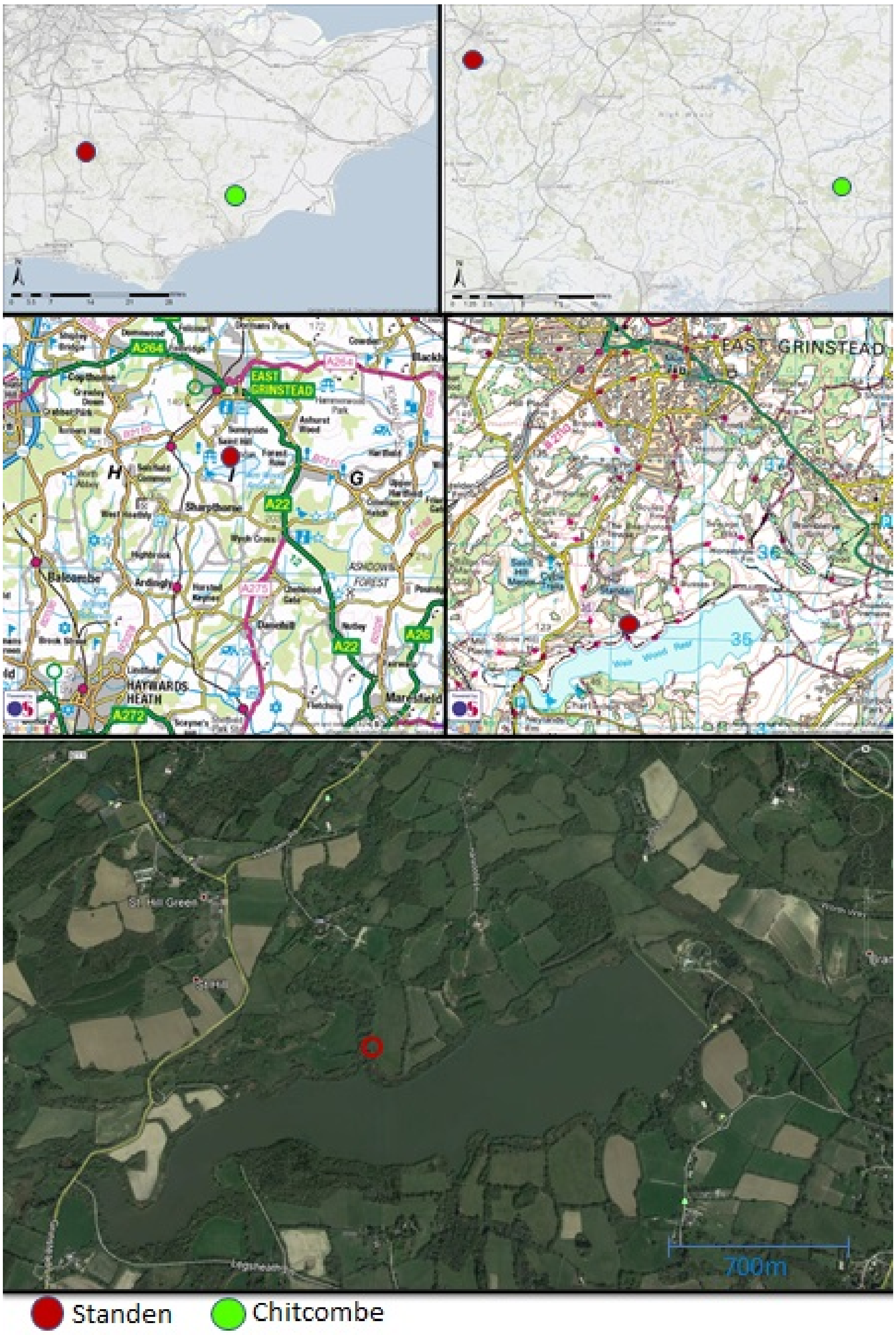


FIGURE 6.1: Position map of Standen

6.1.1 Location

The Roman iron production site of Standen (national grid reference 538900 135600), is situated on the modern-day boundary of Standen House, National Trust, and Busses Farm, approximately two miles south of the town of East Grinstead, in the northwest of the high Weald. The site itself is positioned on the top of the eastern side of a small ghyll that has a stream in its base. This stream is a tributary that runs into Weir Wood reservoir, which is a modern-day expansion of the river Medway. Standen House is a late-Victorian Arts and Crafts movement house with extensive lands, including formal and kitchen gardens, along with meadows and ancient woodland. The site and all its lands are managed and maintained by the National Trust.

6.1.2 Previous Investigation

There has been very little research undertaken on the iron production site at Standen. The earliest reference to this site is by Straker (1931). This is an extremely brief reference to the site with details of location and a single sentence description, 'This is a fairly extensive bloomery, partly in a wood and partly in a field now grass'. Straker returned to the site with Mason, in 1939 to undertake a small investigation. This investigation was undertaken due to the proximity of the site to a number of other Romano-British iron production sites, including Ridge Hill and Walesbech (Straker and Mason, 1939 153). A number of trenches were dug on the northern side of the site with the depth of industrial waste being around "12 to 15 inches" (30-45cm). This depth of deposit is said to be the same across the site which is believed to be "50 yards"

FIGURE 6.2: View over the field and wood which forms Standen iron production site

(45m) in diameter. Fourteen fragments of pottery were discovered, of which 13 were attributed to local ware from the Roman era and the other being a piece of Samian ware that was dated to the second century AD. Reference is made to an 'old boundary bank' which is formed entirely from cinders (Straker and

Mason, 1939 154).

Since then the main archaeological and historical research in the area has been based around the estate. A survey was undertaken by Higgins (1988) surveying the cottages on the estate. The next reference to the site is not then until 2011, when a building and landscape survey was undertaken by Archaeology South East on behalf of the National Trust. This survey focused on the land belonging to Standen House and mentions the Romano-British iron production site and its potential archaeological importance. No excavations were undertaken as part of this survey (James, 2011).

Standen holds four non-statutory designations; Registered Historic Parks and Gardens, Ancient Woodland (including parts of Hollybush Wood within which the iron production site is situated), Archaeologically Sensitive area, which covers the iron production site, and Area of Outstanding Natural Beauty which also encompasses the entire site.

6.1.3 Aims and objectives

The aims set out here are the general aims for the case study and are therefore the same in Part A and B. The objectives will be different as they are specific to the datasets being covered.

Aims:

- Understand the organisation of the iron production site at Standen.

- Test methods for investigating iron production sites to calculate the horizontal and vertical extent of deposits with a focus on the technological waste deposit.
- Quantify and characterise technological waste to gain a true understanding of what forms the technological waste deposits and the development and changes that occurred in technological processes.

Objectives:

- Use a combination of geo-prospection techniques to investigate the spatial distribution of features across the site.
- Use a combination of geo-prospection techniques to investigate the spatial form of anomalies and features, namely the technological waste deposit.
- Use a combination of geo-prospection surveys to understand the different physical responses of features.

Before any work took place on site, landowners were contacted and all appropriate permissions granted.

6.2 Field Strategy and Data Collection

All four available geo-prospection surveys were used to assess the site (fig 6.3). These include magnetometry, Earth Resistivity Tomography (ERT), Induced Polarisation (IP), and Electromagnetic, in-phase and quadrature, surveys. All these surveys were conducted in the summer of 2017. How these survey types work, what anomalies they can detect, and the specific apparatus being used in this project is set out in Chapter 3. Why and how these surveys were deployed in the field throughout this case study will be set out here. All raw data collected can be seen in Appendix C.1.

FIGURE 6.3: Geo-prospection survey grids.
Black=Mag, Red=ERT/IP, Blue=EM

6.2.1 Magnetometry

As has been discussed in Chapter 3 magnetometry is widely used in archaeology and is highly applicable in detecting features and anomalies that would be expected on iron production sites. A magnetometer survey had been completed by the National Trust at Standen. However, this only covered part of the site so the decision to use this technique for this project was to gain a raw dataset that covers a larger portion of the site.

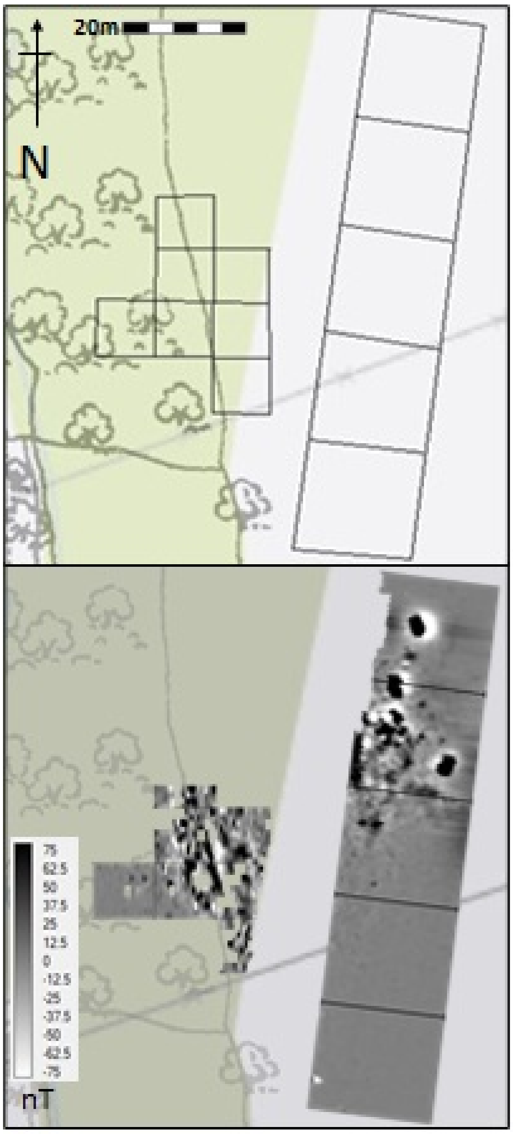


FIGURE 6.4: Plan of magnetometry survey grids, and example data

The magnetometry survey was completed across the site in the summer of 2017 (fig 6.4) using a Bartington Grad 601 twin probe, with the detection limit, the highest magnetism this is recorded, set to 1000nT rather than the standard 100nT. Although this loses a small amount of definition between 0-1nT, it allows for a greater understanding of anomalies between 100-1000nT. Many features within this magnetic range would be expected on an iron production site. Grid squares of 20mx20m were used in the open field and 10mx10m used in the woodland.

Both these sizes were seen as the most manageable and efficient size for a single person to set up and move while surveying. In the 20mx20m grids, line transects were set to 1m with 8 readings being taken per meter along the transect, giving 1600 readings per grid. In the 10mx10m grids, line transects were set to 1m with 4 readings per meter, taken manually, giving 200 readings per grid. Both surveys raw data are set out in AppendixC.1.1 with a full interpretation given in section 6.3.1.

6.2.2 Earth Resistivity Tomography

Resistivity surveys are commonplace in archaeology and their responses well understood. Earth Resistivity Tomography (ERT) is applicable for this case study as it can detect a number of features expected on an iron production site. The main reason for the use of this technique is due to it taking readings as a vertical section through the ground. This then allows for the investigation of the vertical extent of deposits, namely, the technological waste deposit, which is one of the aims of this project.

The ERT surveys were completed across the site in the summer of 2017 (fig 6.5). These were completed using the ZZ FlasRes64, utilising two different electrode

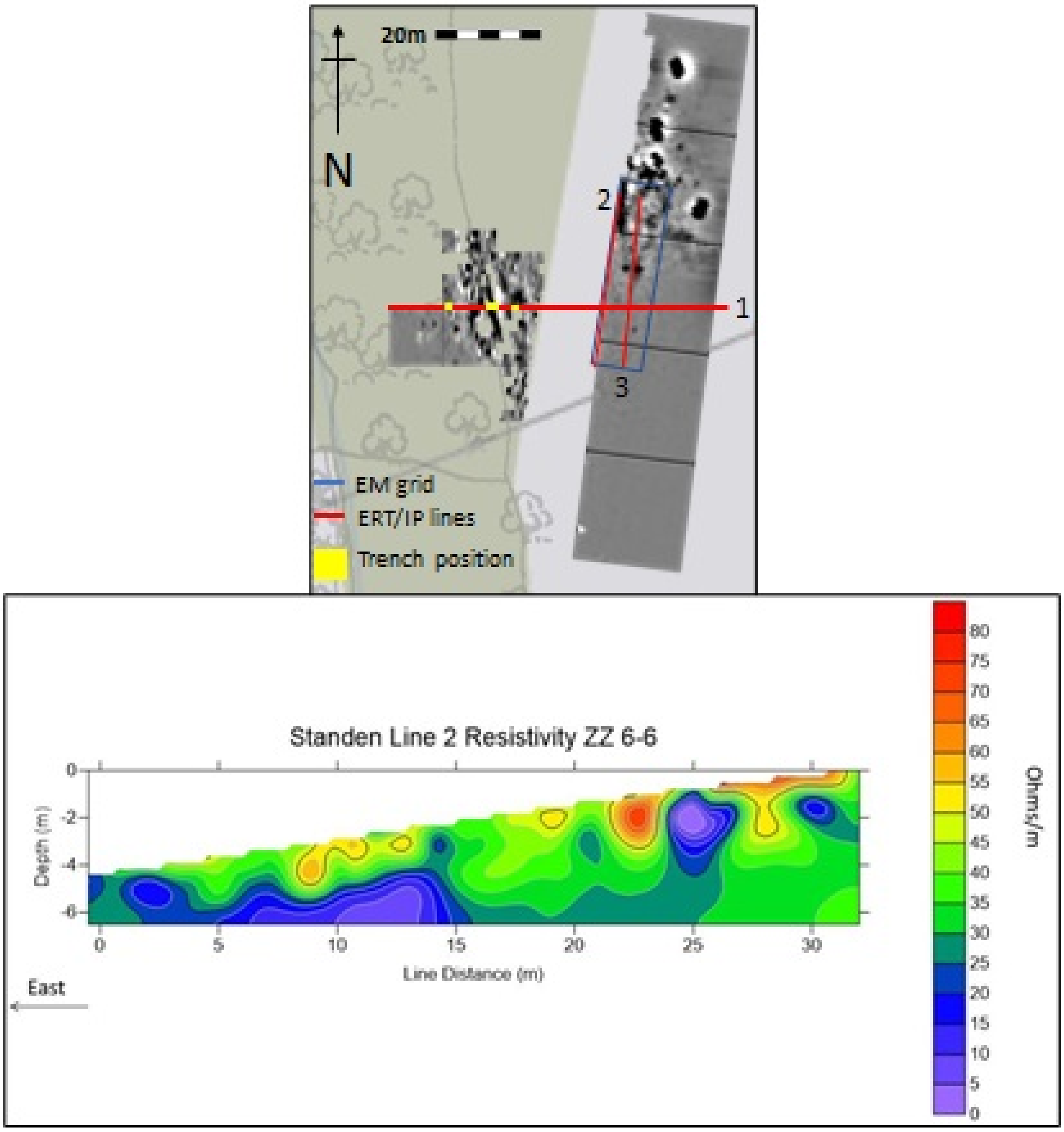


FIGURE 6.5: Standen ERT/IP survey line positions with example ERT data

spacing, 1m and 0.5m. These give survey line lengths of 64m and 32m respectfully. The survey lines were completed across the field and woodland based on interpretations from the magnetometry survey (fig 6.4) and physical constraints in the field.

Three lines were surveyed using ERT in the summer of 2017 (AP.C.1.2). Lines 2 and 3 were carried out parallel to each other within the field with line 1 transecting lines two and three and covering the extent of the site across the field and woodland. These surveys detected a number of anomalies of varying resistivity distributed across all survey areas. The interpretation of these anomalies is set out in section 6.3.2.

6.2.3 Induced Polarisation

The use of Induced Polarisation in the mining industry to identify disseminated ores, including iron ores, shows this technique could be applicable to this case study in identifying this specific material, primarily in the technological waste deposit. As discussed in Chapter 3, this data was collected at the same time as the ERT survey, also giving a vertical slice through the ground. Using this technique at Standen therefore helps to fulfil one of the aims of this project.

The Induced Polarisation surveys were completed in the summer of 2017 (fig 6.6) using the ZZ FlasRes64, utilising two different electrode spacing, 1m and 0.5m. These give survey line lengths of 64m and 32m respectfully. The survey lines were completed across the field and woodland based on interpretations from the magnetometry survey and physical constrains in the field.

Line 1 extends across the site covering the woodland and field. Lines 2 and 3 transect line 1 in the field (ap C.1.3). These surveys detected a number of anomalies of varying polarisation distributed across all survey areas, which will be interpreted in section 6.3.3.

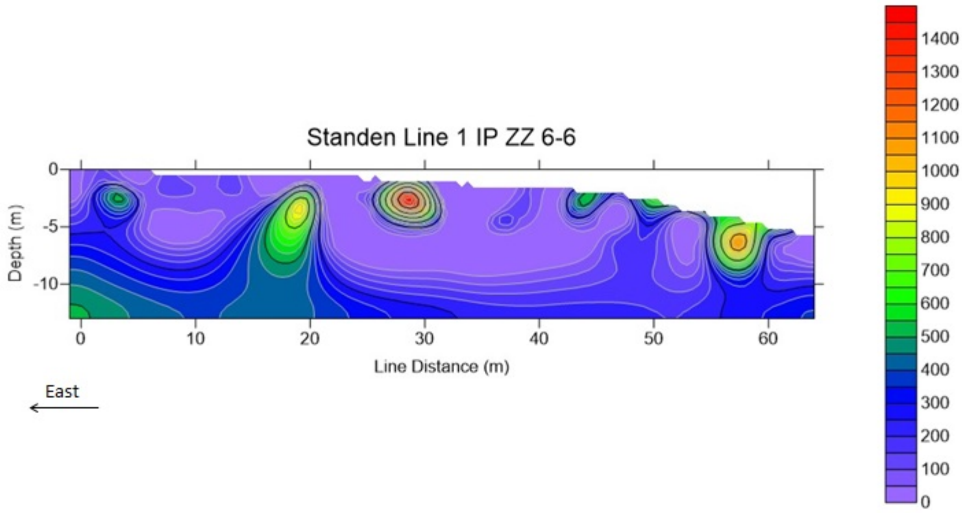


FIGURE 6.6: Example of raw IP data from Standen

6.2.4 Electromagnetic

EM surveys were used at Standen as they met the aims of this project mapping features in both the horizontal and vertical plane. Moreover, as an approach that is not commonly used on archaeological sites, their use in this project allow for it to be tested and a database started.

The Electromagnetic surveys were completed across the site in the summer of 2017 using a GSSI EMP400. In-phase and quadrature were both recorded at 3kHz and 15kHz. The surveys were based in the open field due to physical constraints of using this survey type in woodland (fig 6.7).

A survey was carried out covering an area of 9m x 33m. The survey collected in-phase and quadrature data at both 3kHz and 15kHz therefore four data-sets

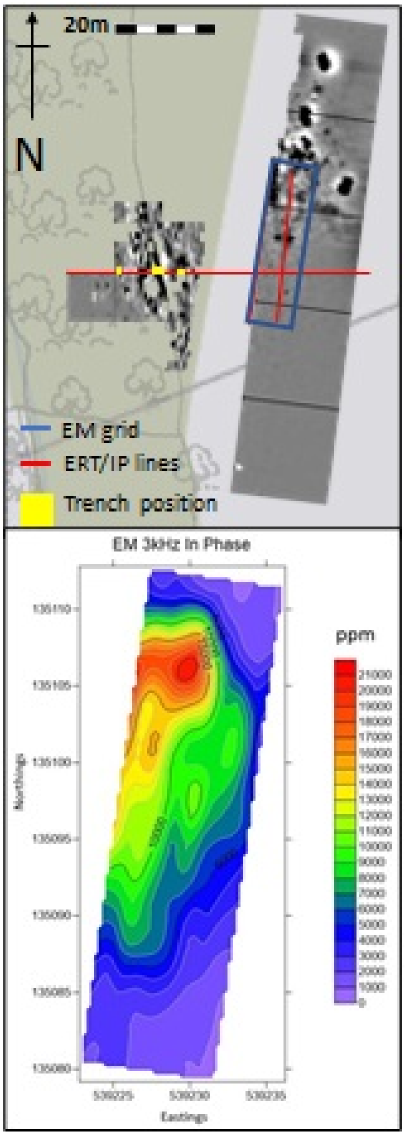


FIGURE 6.7: Standen EM in-phase and quadrature survey grids, with example dataset (in-phase 3kHz)

and survey images were created for the survey (ap C.1.4). The in-phase surveys show a single large area of increased magnetic susceptibility surrounded by lower magnetic susceptibility. The quadrature surveys show a number of anomalies of mixed conductivity. These surveys will be interpreted in greater depth in section 6.3.4.

6.3 Interpretation of Primary Datasets

All raw data, shown in AppendixC.1, was normalised and annotated with an accompanying form setting out key anomalies and other observations. These can all be found in AppendixC.2.

As explained in Chapter 4 section 4.3 only a single example of ERT, IP, EM in-phase, and EM quadrature will be individually interpreted to allow the reader an understanding of the process with all other data in Appendix C.2. All relevant data will be drawn together in chapter 8 for the analysis of key features. Both field and woodland magnetometry surveys will be interpreted in this section to give a full overview of features at Standen and act as a reference point for other survey types.

As previously discussed the key anomalies, technological waste deposits (TWD), furnaces, ditches and working areas, are specific features that will be used in the wider interpretation and discussion of the organisation of the site.

6.3.1 Magnetometry

A number of data processing steps were carried out on the raw magnetometry data to standardise the data for better comparison and understanding. This included 'zero mean grid', 'zero mean traverse', and 'interpolate' in the X and Y axis. The data was then clipped to +/-75nT.

Both field and wood magnetometry surveys will be interpreted together here to give a full interpretation of the site (fig 6.8). Both these surveys can be found individually in Appendix C.2.1. The interpretation categories are the same as used at Chitcombe and are set out in Chapter 4 section 4.3.1. At Standen only three of the interpretation categories have been identified. Furnace (red), Primary deposit (light blue), and secondary deposit (dark blue).

Furnace (Red)

In the field survey there are three anomalies with magnetism up to 1000nT what have been interpreted as furnaces. All three of these anomalies have a very similar shape, which along with the similar high readings could show a standardisation in construction. Two of these furnaces are positioned next to an area of secondary deposition, one to the north and one to the east. These may then, in some part, be organised around this area, or this area has been defined due to the smelting taking place. The third furnace is slightly to the north. A possible explanation for this positioning is that it could be a furnace constructed at a different time to those around the secondary deposit. This could show a possible discontinuity in use and a slight change in working area.

Primary deposition of technological material (Light blue)

The only area of primary deposition of material is in the wood survey and has been interpreted as the TWD. This interpretation is backed up by its position on the side of the bank heading towards a small stream. On the eastern edge of this area is a single linear anomaly running in a rough north-south direction.

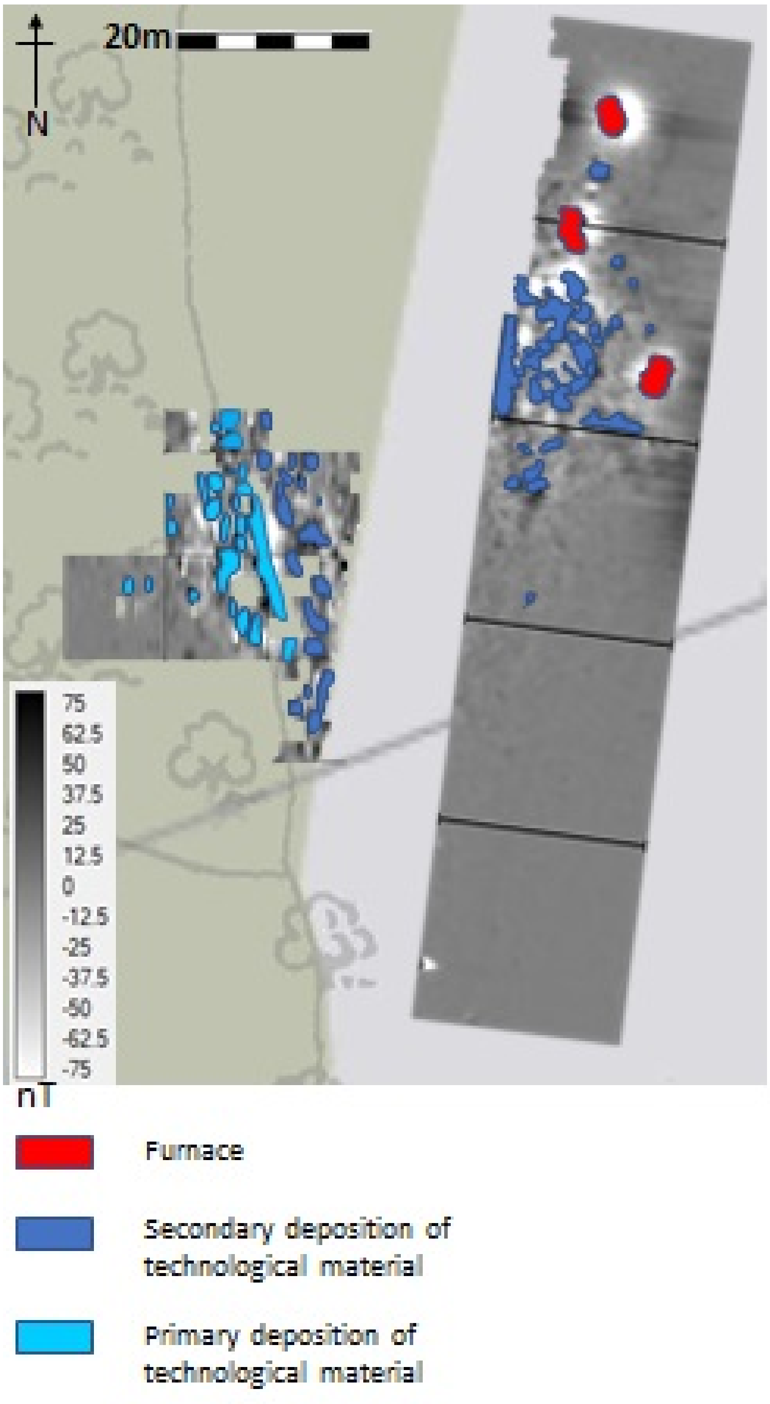


FIGURE 6.8: Interpreted Standen magnetometry survey

This is the old field boundary and everything to the west of it down the bank has been interpreted as the TWD because it would not have been moved by ploughing but stayed in its initial position.

Secondary deposition of technological material (Dark blue)

There is an area of secondary deposit in both the field and the wood surveys, both with different interpretation. The area in the field can be interpreted as a working area due to its proximity and arrangement with the two furnaces. There is a possibility that this area has been purposefully covered in material to form a hard standing, but more likely is accidental deposition of material during smelting and discard into the TWD. The secondary deposition anomalies in the wood survey are interpreted as technological debris, and could have formed part of the TWD. However, due to heavy ploughing on the eastern side of the field boundary, all this material has been moved and mixed and therefore is no longer a primary deposit.

6.3.2 Earth Resistivity Tomography

To normalise the survey images for ERT the scale was set to 1-136 ohms/m. This is the maximum scale range across Standen. By normalising the survey images the colour scale is the same throughout all surveys making anomalies easier to compare.

The example being used to discuss ERT is Line 1 (Fig6.9), with all other ERT lines interpreted in AppendixC.2.2. The layout of the interpretation datasets for ERT is the same as set out in Chitcombe, Chapter 4 section 4.3, where an explanation of the interpretation categories can be found.

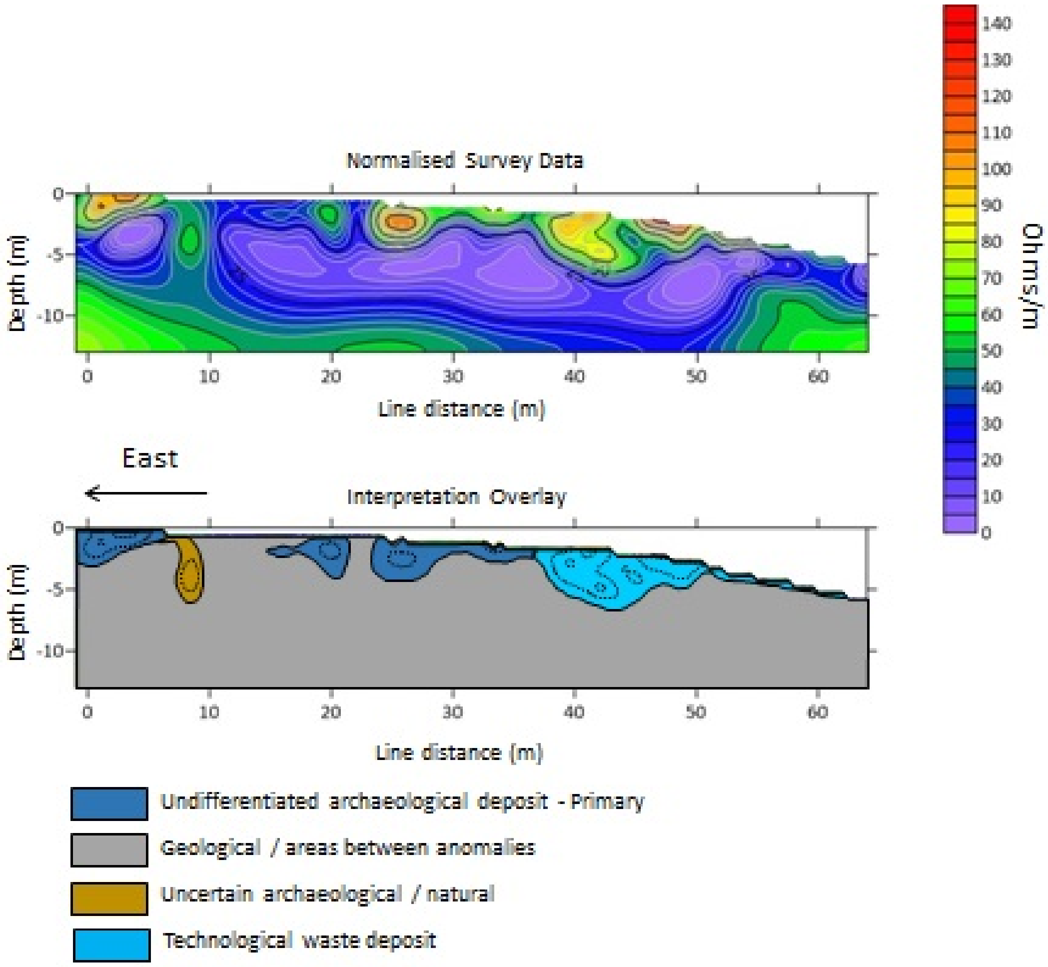


FIGURE 6.9: Annotated Standen ERT line 1

Only one of the key anomalies has been identified within this survey line which is the TWD (light blue). This extends along the ground surface from 36m to 61m. It consists of a number of anomalies ranging from 40-140 ohms/m. A variety of anomalies would be expected from the response of a TWD as it is heterogeneous in its formation. The TWD does not extend further east due to information from the mag survey and observation of the crossing of a field boundary meaning the deposits would have been effected by ploughing and therefore cannot be guaranteed to be in-situ. Moreover, it is unclear from the magnetometer survey where the working area in the field turns into the TWD (fig 6.8) as an area could not be surveyed due to a dense hedge. For this reason the increased resistivity anomalies have been interpreted as primary undifferentiated archaeological deposits (UAD).

6.3.3 Induced Polarisation

To normalise the induced polarisation survey the mean value was taken from all the upper values to create the scale which is 0-1039 units. This was decided as there are over 1000 units difference between the Lines 1 and 3, and Line 2, meaning a full scale range would have lost definition in Line 2 and a lower range could have caused lack of definition in Lines 1 and 3.

The example used to discuss the Induced Polarisation surveys is Line 1 (Fig6.10), with all other IP lines interpreted in AppendixC.2.3. All interpretation categories are the same as ERT, as set out in Chapter 4 section 4.3. Two key anomalies were picked out for this line.

Only a single key feature was identified in Standen IP line 1, the TWD. The TWD does not present itself as a single continuous feature as in ERT line 1 (fig 6.9) but rather as four identifiable discreet deposits measuring from 200-1400. This can be interpreted as showing the response to IP in the TWD is from a specific type of deposit and not the general spread of technological waste.

There is a large section of uncertain archaeological/natural that extends around

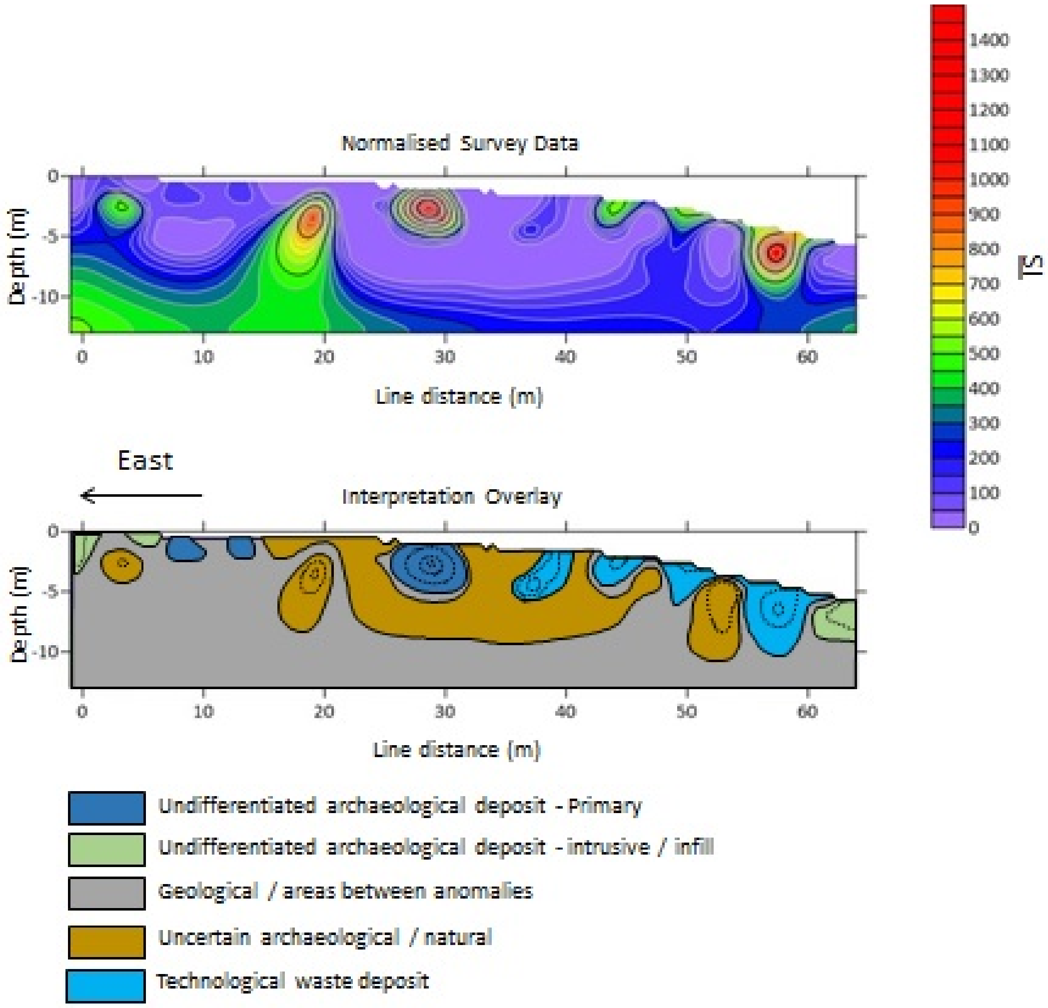


FIGURE 6.10: Annotated Standen IP line 1

30m from within the area of the TWD to the east with other discreet anomalies with this designation. These deposits extend up to the ground surface and could represent a non-response from the TWD. However, as these are such large anomalies with no sub-definition it cannot be said for sure if and where this represents archaeology or natural.

The UADs in this line 1 are along the ground surface and interpreted as possible spread of archaeological debris.

6.3.4 Electromagnetic - In-phase

As only one set of EM surveys was completed at Standen the data cannot be normalised. The images, for both in-phase and quadrature, have therefore been kept at an individual maximum/minimum scale range.

The 15kHz survey (Fig6.11) will be used here as the main example for discussion, with all other EM surveys set out in AppendixC.2.4. Only a single key anomaly was identified within this survey. Anomaly (A) is an area of increased magnetic susceptibility centred on 539230E, 135100N with readings ranging between 8000-24000 ppm. The highest reading of 24000 ppm is centred on 539230E, 135107N. This has been interpreted as a working area with the main deposit of material where the highest readings are. This was chosen as a key anomaly as it helps meet the aims of this project investigating the organisation of the site.

There is only one other observation in this survey and that is that in the north-east and south-east corners of the survey the magnetic susceptibility decreases to 3000 ppm. This decrease is seen to represent the response from the natural geology, but with large amounts of ploughing care must be taken with this interpretation.

The 15kHz (AppendixC.2.4,FigC.21) and 3kHz (AppendixC.2.4,FigC.22) surveys are directly associated as they are completed at the same time. Changes in the data between the two surveys and the interpretations for this will be discussed in Chapter 8.

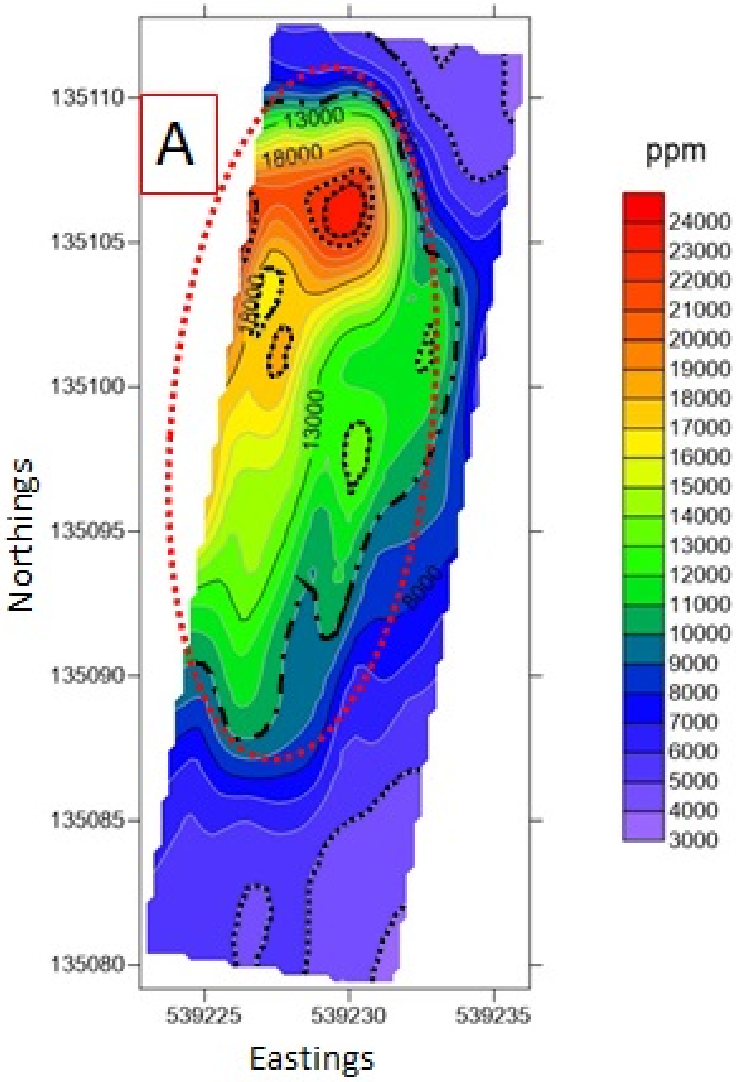


FIGURE 6.11: Annotated Standen in-phase 15kHz

Electromagnetic - Quadrature

The 3kHz (AppendixC.2.4,Fig6.12) survey will be used here as the main example for discussion. One key anomaly (A) was identified within this survey, an area of mixed low conductivity centred on 539228E, 135100N, with readings in the main area between 0-200 ppm which forms a slight curved line. This

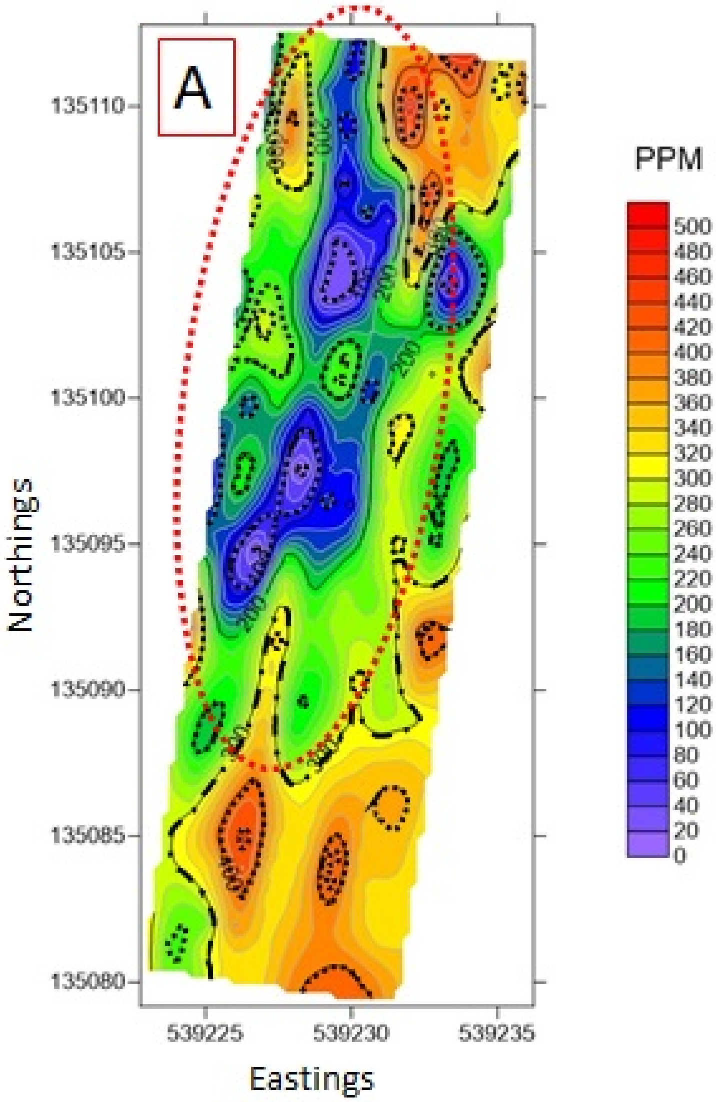


FIGURE 6.12: Annotated Standen quadrature 3kHz

anomaly is within the working area as interpreted through the magnetometer and in-phase surveys. With the anomaly forming a roughly linear feature. an interpretation could be made of a pathway through the working area where the material, most likely smelting waste, has been compacted into a path. This was chosen as a key anomaly as it helps meet the aims of this project investigating the organisation of the site.

There is only one observation in this survey and that is that in the north-east and south-east corners of the survey the conductivity increases to up to 500 ppm. This increase is seen to represent the response from the natural geology.

It can be seen that the anomalies between the 15kHz and 3kHz surveys are completely different in both their appearance and data-ranges. This shows a complete change in the deposit with either two separate phases of deposition or a heavy influence in the 15kHz survey from ploughing.

6.4 Discussion

The use of geophysical surveys to estimate the depth and volume of the waste deposit shows potential in this study, but caution must be taken. In all three ERT surveys (fig C.15, C.16 and C.17) a higher level of resistivity was seen towards the surface which was in some cases mimicked by the Induced Polarisation data (ap C.2.3). When looking at the excavation data it could be said that this higher resistivity near the surface is due to the waste deposits on the surface having a higher resistance than the natural geology of underlying clay. However, a caveat should be placed on this as there are also large sandstone outcrops in the local vicinity of the site. If there are also outcrops within the natural geology underlying the site this may cause some of the higher readings at greater depths. Overall, when comparing these two types of surveys, it can be seen that there are similarities and differences. With a lot of these responses on the very near surface and assumed to be in the archaeological deposit it can be theorised that it is not the same material leading to high readings in both surveys but that they are both involved in the iron production process and therefore end up in the waste deposit together.

The magnetometer survey has allowed an understanding of the horizontal extent of the site and position of features (fig 6.4). However, care must be taken as there is a chance this is an exaggerated extent due to the effect of ploughing spreading the material on the east of the boundary bank. The survey has also shown areas with a very high magnetic response which, to a high probability, are the remains of the furnaces.

The in-phase and quadrature surveys give information on the potential depth of material giving its information in the horizontal plane rather than the vertical plane like the ERT and IP. This can be used to assess the preservation of the site as it gives three dimensional information on deposits. This is most clearly seen with the quadrature survey which shows a complete change in deposit between the 15kHz and 3kHz survey. With direct comparison between the in-phase and quadrature, the two physical reactions of anomalies can be compared. This can be seen in the 3kHz survey where the areas of low conductivity match the areas of increased magnetic susceptibility, possibly showing a specific material holding both properties.

7 Case Study 2 : Standen – Part B – Excavation and Deposit Sampling

7.1 Introduction

The geo-prospection investigation of the site at Standen was covered in chapter 6. This chapter will cover the excavation, deposit sampling, and material classification that occurred during this case study. All supporting datasets for this chapter can be found in Appendix D.

All background information for the site including location, and all previous investigation of the site has been covered in the introduction section to chapter 6 so will not be repeated here.

7.1.1 Aims and Objectives

Aims:

- Understand the organisation of the Roman iron production site at Standen.

- Test methods for investigating iron production sites to calculate the horizontal and vertical extent of deposits with a focus on the technological waste deposit.
- Quantify and characterise technological waste to gain a true understanding of what forms the technological waste deposits and the development and changes that occurred in technological processes.

Objectives:

- Excavate a number of test pits of known volume into the waste deposit to ground truth the geo-prospection data.
- Excavate a number of test pits of known volume into the waste deposit to generate data sets of technological waste with which to help quantify the makeup of the waste deposits.
- Analyse the technical waste on a macro scale to quantify and characterise, constituent volume, technological processes and dynamics of deposition.

Before any work took place on site, landowners were contacted and all appropriate permissions granted.

7.2 Field Strategies and treatment of material

Three trenches were excavated across this site producing datasets for analysis. The general approach to excavations, deposit sampling, and classification was set out in chapter 3. How and why these strategies were applied to this case study will be set out in this section. All excavation on site occurred in the summer of 2017.

7.2.1 Excavation and deposit sampling

For the investigation of the iron production waste deposits it was decided the best approach would be to use spit excavation. This use of spit excavation allowed for a standard and repeatable practice for the collection of technological waste to meet the aims of this project.

Excavation

Once excavations had started it was decided that the spits would have a depth of 0.1m in order to gain a high resolution through the waste deposits. This decision was reached as the majority of technological waste fragments were smaller than 0.1m, so there was less chance of large fragments spanning multiple spits. This was changed to spits 0.2m in trench 3 as the archaeology had been extensively disturbed by ploughing.

The gauge of the sieve used at Standen to divide the size categories was decided based on use and observations made during fieldwork at Chitcombe. By using the same 6mm and 25mm sieves, the datasets from both sites would be comparable.

Treatment of spit material

At Standen all mixed large (>25mm) was collected, 25%wt of all mixed small (>6<25mm with attached mixed matrix) was collected, and 10%wt of all the

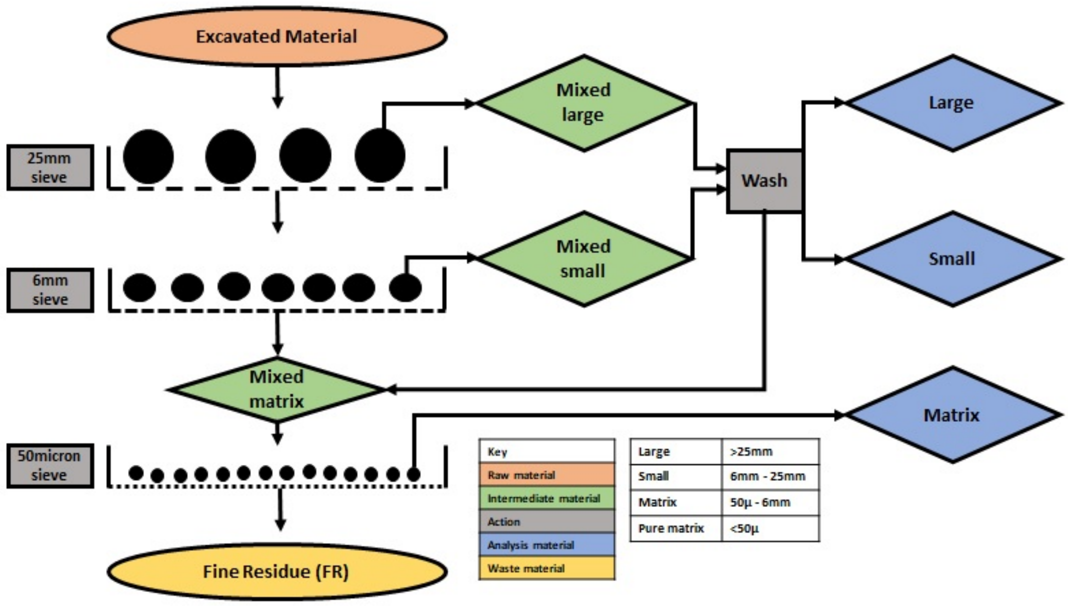


FIGURE 7.1: material excavation schematic

mixed matrix (<6mm) was sampled (fig 7.1). A note should be made here that the weather while excavating was very wet, this meant in a number of spits in trench 1 the fill was too wet to pass through the 6mm sieve on sites, and was therefore collected (designated small+matrix) and sieved off-site to be prepared for analysis. The methods for the excavation of the waste heap is set out in full in Appendix D.1.

Before analysis could take place, all material had to be manually washed to remove the sticky Wealden clay. The 'Small+Matrix' material was allowed to dry so sieving could take place. A 1kg sub-samples of the mixed small and mixed matrix were tied into large pieces of 50μ mosquito netting and washed under flowing water until it ran clear. This process was time consuming but entirely necessary.

Out of the three trenches excavated in this case study it was decided that only

FIGURE 7.2: Excavations of T1, Standen

trench 1 should be used for analysis, and that due to time constraints, and to be comparable to the data from case study 1, every other spit would be used for analysis.

7.2.2 Classification

Once all material had been washed it was stored according to spit and size category ready for classification. All size categories were dealt with a spit at a time. The large category was emptied into a sorting area and manually split into groups according to appearance, these were not pre-determined. This included material type, surface textures, and a number of other factors which were then recorded across the group on a classification proforma sheet. Examples and descriptions of the types ca be found in Appendix D.4. This was repeated with every spit. The reasoning for not splitting the material into pre-determined groups was so that material was not forced into categories but rather formed its own creating a non-biased approach to the classification.

FIGURE 7.3: Sorting of Matrix size category

The small and matrix were only split into material categories (slag, furnace material, and geological) for quantification purposes (fig 7.3), with notes taken on anything that was identified as unique, for example spheroidal slag.

7.3 Discussion of Primary Datasets

A number of datasets have been created throughout the excavation. This includes trench information, weight information by material, size, and type (AppendixD.3), and classification data (AppendixD.5). Examples of the data will be discussed in depth in this section for a greater understanding.

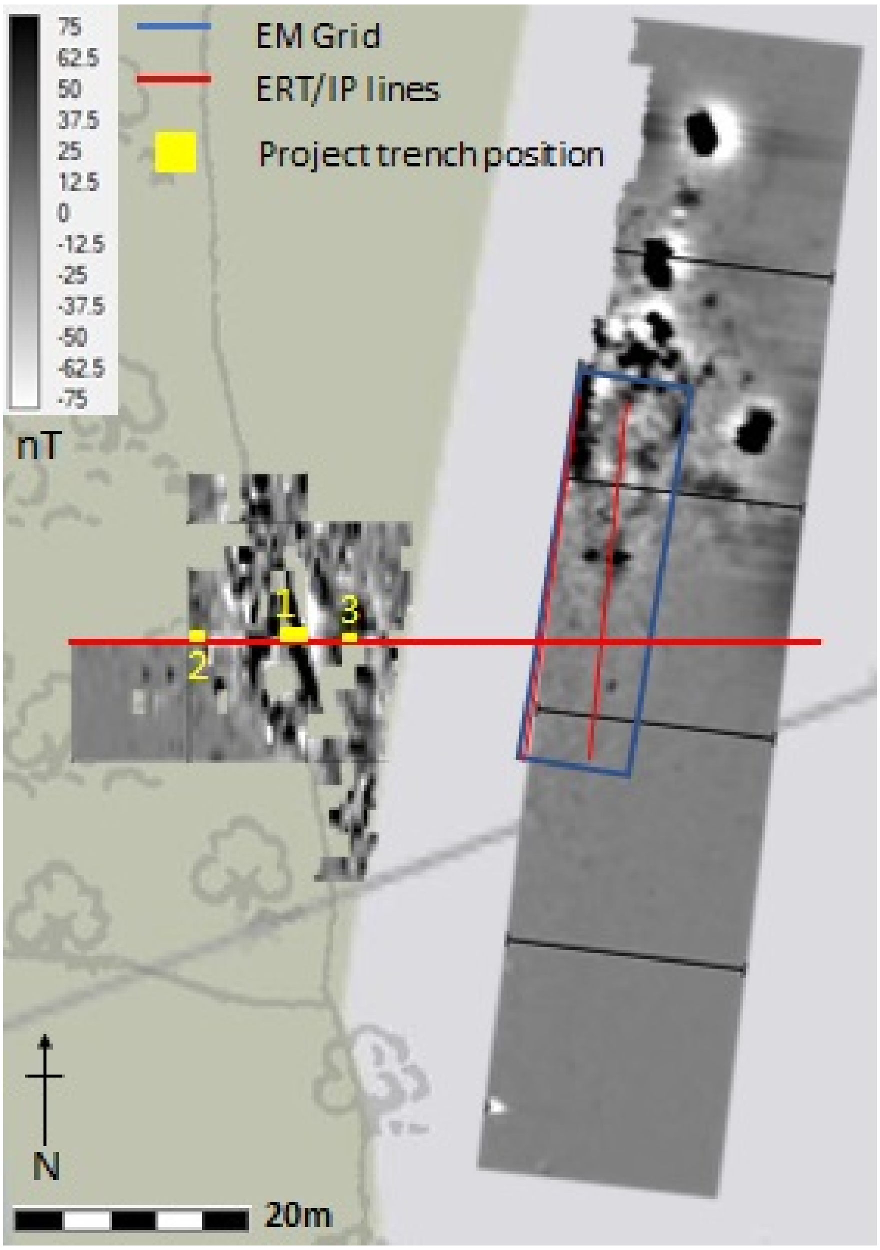


FIGURE 7.4: Standen trench position

7.3.1 Trench overview

This section will outline the three trenches excavated for this case study was a more in-depth discussion in Appendix D.2. There position relative to the site can be seen in figure 7.4.

Trench 1

Trench one (fig.7.5) measured 2m by 1m and had a maximum depth of 0.92m, giving a volume of 1.84m^3, consisting of nine spits and three contexts 101, 102 and 103 (fig.7.6). A full range of technological waste was discovered with the total weight of material removed from T1 was 2005.5kg. Of this 883.25kg was matrix, 568.2kg was large samples, 554.05kg was small samples (ap D.3.1).

FIGURE 7.5: Standen T1

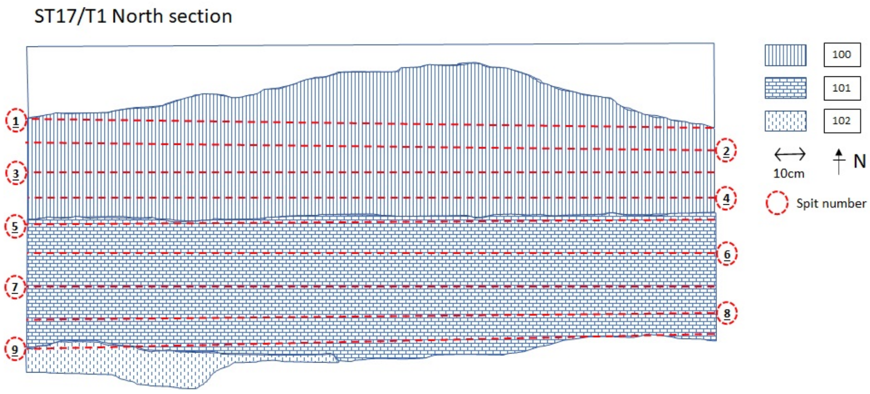


FIGURE 7.6: North section of trench 1, Standen

Trench 2

Trench two (fig.7.7) measured 1m by 1m and had a maximum depth of 0.52m, giving a volume of 0.52m^3, consisting of three spits and two contexts 201 and 202 (fig.7.8). A full range of technological waste was discovered with the total weight of material removed from T2 was 515.7kg. Of this 211.6kg was matrix, 229.4kg was large samples and 137.7kg was small samples (ap D.3.1).

FIGURE 7.7: Standen T2

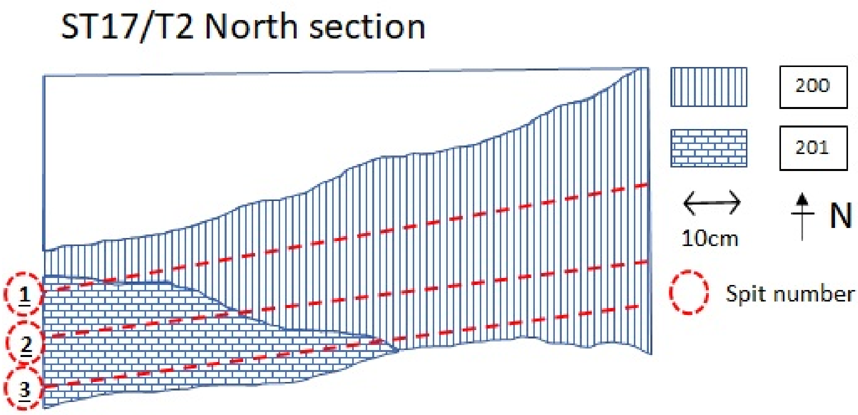


FIGURE 7.8: North section of trench 2, Standen

Trench 3

Trench three (fig.7.9) measured 1m by 0.5m and had a maximum depth of 0.53m, giving a volume of 0.27m^3, consisting of two spits with only a single obvious context (fig.7.10). A full range of technological waste was discovered with the total weight of material removed from T3 was 294.2kg. Of this

147.4kg was matrix, 71kg was large samples and 119.48kg was small samples (ap D.3.1).

FIGURE 7.9: Standen T3

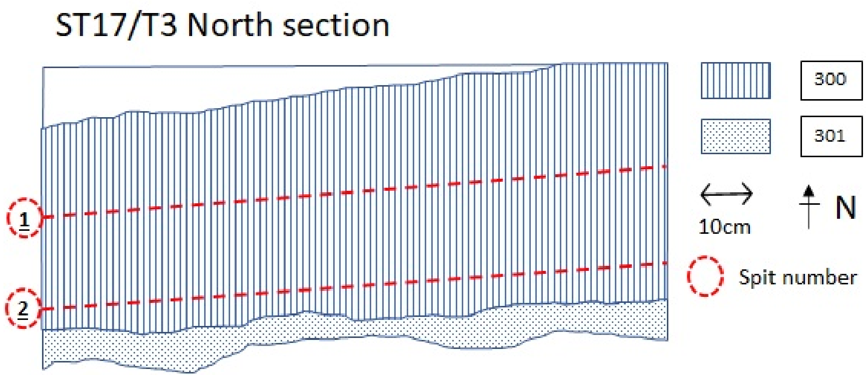


FIGURE 7.10: North section of trench 3, Standen

7.3.2 Quantification of technological waste

The material collected during excavation can be quantified in a number of different ways. This includes by size category and by material type. This is all set out in Appendix D.3. A number of these tables will be used here to discuss them in depth so that all the tables can be understood.

The first to be discussed will be the total material by spit (tab.7.1, fig.7.11). The 'spit weight' category gives the total weight of all material from the spit. Despite the spit being near-uniform in dimensions the data shows considerable variation in spit weight, ranging from 73.15kg to 306.20kg, as difference of 233.05kg. A difference would be expected as a the formation of these spits is not homogeneous, therefore if a spit had more dense slag and less matrix, or less dense furnace material, it would be heavier than those with more matrix. The main reason for the difference between spit 1 and 9 is that spit 9 was not complete as it sits at the bottom of the trench on the natural, although a standard size was attempted this was not always possible. It can be noted that there is a gradual and consistent decrease from spit 1 to 7.

TABLE 7.1: Standen trench 1 - Quantification of total analysed material by spit level (kg)

Spit	spit weight	slag	FM	geo	FR	Total
1	306.20	94.24	13.00	5.23	193.74	306.20
3	297.70	83.19	8.44	7.93	198.14	297.70
5	268.70	114.11	17.32	4.78	132.49	268.70
7	206.90	81.58	11.51	5.40	108.40	206.90
9	73.15	20.13	5.27	1.28	46.47	73.15
Total (kg)	1152.65	393.26	55.53	24.63	679.24	1152.65

The next four column headings denote the quantification by material category after sorting (slag, furnace material, geological, and fine residue). The Slag is

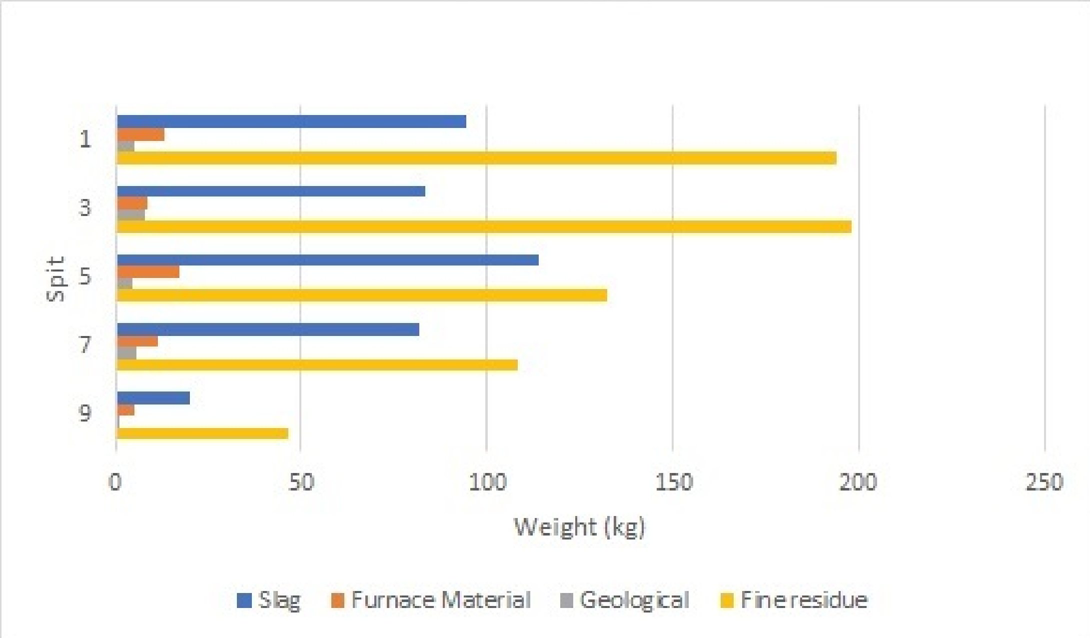


FIGURE 7.11: Total weight of materials by spit, Trench 1 Standen (kg)

defined as any sample that was fully or primarily formed of slag. Furnace material (FM) is defined as any material formed of fired clay or vitrified clay. Geological is defined as any stone material, this includes, but not limited to, sandstone, and raw or roasted iron ore. The fine residue is the remaining weight of the spit and is defined by material below 50μ.

When looking at the overall weights of the spits of T1, it can be seen that the most common material by weight is fine residue (<50μ), followed by slag, furnace material and the least frequent, geological. When this is calculated by percentages by weight of materials throughout each spit and averaged then it shows us that 59.0%wt is fine residue, 33.6%wt is slag, 5.3%wt is furnace material and 2.1%wt geological.

Quantification of sub-samples from Trench 1

It was decided, due to processing times and length of this project, that a 1kg sub-sample would be analysed for the mixed small and mixed matrix. The weights from the sub-samples will then be extrapolated to calculate the representation in the whole spit. Two tables have been created for each category as can be seen in appendix D.3. The matrix category will be discussed here for clearer understanding.

TABLE 7.2: Standen trench 1 - Quantification of 1kg sample of mixed matrix by spit level (kg)

Spit	MMa	matrix	slag	FM	geo	FR	total
1	1.000	0.075	0.046	0.010	0.019	0.925	1.000
3	1.000	0.100	0.058	0.008	0.030	0.900	0.996
5	1.000	0.100	0.064	0.017	0.019	0.900	1.000
7	1.000	0.100	0.062	0.009	0.029	0.900	1.000
9	1.000	0.100	0.062	0.018	0.020	0.900	1.000
total	5.000	0.475	0.292	0.062	0.117	4.525	4.996

The first table (tab.7.2) sets out the weights calculated from the 1kg sub-sample. The mixed matrix (MMa) column gives the weight of the sub-sample. This was washed through 50μ mesh separating into matrix, material $<6\text{mm}>50\mu$, and fine residue (FR), material $<50\mu$. The matrix was then sorted into material categories, slag, furnace material (FM), and geological material (geo). These materials are set out by spit and weight of the sub-sample.

The second table (7.3) sets out the extrapolated data for the matrix samples obtained from the 1kg sub-sample. The mixed matrix (MMa) column on this table sets out the complete weight calculated from excavation weights, and that washed off when cleaning the mixed large and mixed small. This known

TABLE 7.3: Standen trench 1 - Quantification of extrapolated mixed matrix by spit level (kg)

Spit	MMa	matrix	slag	FM	geo	FR	total
1	209.44	15.71	9.63	2.09	3.98	193.74	209.44
3	219.18	21.04	12.71	1.75	6.58	198.14	219.18
5	147.21	14.72	9.42	2.50	2.80	132.49	147.21
7	120.45	12.04	7.47	1.08	3.49	108.40	120.45
9	51.64	5.16	3.20	0.93	1.03	46.47	51.64
total	747.92	68.68	42.44	8.36	17.88	679.24	747.92

weight is then used as the constant for the extrapolation equation. This equation is $X(\frac{Y}{1000})$, where X is the weight of the material from the sub sample in table 7.2, and Y is the complete MMA weight.

The geological material from spit 2 will be used here as an example to show the workings of the extrapolation equation. The weight in the sub-sample is 30g (tab.7.2) and the complete weight of MMa is 219179g (tab.7.3), forming the equation $30(\frac{219179}{1000})$ which equals 6575g. This was repeated for all slag, FM, geo, and FR sub-sample weights.

Classification and typologies

A total of 4813 individual samples were classified from T1, forming 43 different types within the broad materials of slag, furnace material and geological (tab 7.4). All classification data can be seen in Appendix D.5.

To meet the aims of this project in investigating the dynamics of the process of smelting and deposition of its waste products, only dominant types will be further looked at for analysis. A dominant type is one that is present in more

TABLE 7.4: Number of samples, types and dominant types across the spits in T1

Spits	1	3	5	7	9
No. of samples	1027	1308	1344	811	332
No. of types	17	20	22	18	14
No. of Dominant types	9	14	13	13	11

than half of the quantified spits (tab.7.5), and represents the consistency of the technology and optimum operation.

TABLE 7.5: Presence of dominate types in analysed spits of T1

Types	1	3	5	7	9	total
Burnt Clay	Y	Y	Y	Y	Y	5
Corrugated	Y	Y	Y	Y	Y	5
FMT	Y	Y	Y	Y	Y	5
Furnace slag	Y	Y	Y	Y	Y	5
Glassy	Y	Y	Y	Y	Y	5
Magnetic	Y	Y	Y	Y	Y	5
Vitrified	Y	Y	Y	Y	Y	5
Dense surface	Y	Y	Y	Y	Y	5
Light porous	N	Y	Y	Y	Y	4
Messy ripple	N	Y	Y	Y	Y	4
Porous surface	N	Y	Y	Y	Y	4
Sandstone	Y	Y	Y	Y	N	4
Smooth	N	Y	Y	Y	N	3

Abbrev. Y=present N=absent

Of these dominant types (type ap D.4), whose representations can been seen later in this chapter in figures 7.16 and 7.17, there are eight present in all five of the spits. These include, burnt clay, corrugated, fluid movement tendril, furnace slag, glassy, magnetic, vitrified mixed furnace material, and dense surface . There are then four types which are present in four contiguous spits. These types include, light porous, messy ripple, porous surface, and sandstone. Only one type, smooth, is represented in three spits. All other types are only represented in one or two spits and therefore non-dominant. Table 7.5 shows that spits 3, 5, and 7 contain all the dominant types. Spit 1 does not contain 4 dominant types and spit 9 does not contain 2. There is only one cross over in these absences and that is the smooth type. The difference in absences of the other types could be important in showing a change in smelting process.

A number of information points were collected on each type during the classification (set out in chapter 3). In appendix D the three most abundant dominant types by weight have been tabulated with their classification information. Across all spits the three most abundant types by weights are dominant types. The data from spit 5 (tab.7.6) will be used here as an example so other classification data can be better understood.

TABLE 7.6: Classification of top 3 dominant types by weight, Spit 5

Type	FMT	corrugated	Glassy
Material	slag	slag	slag
Weight(g)	14225	7400	6750
Number	296	180	154
Min/max size	2.5x3.3 / 8.9x7.8	2.7x2.5 / 11.7x7.6	2.9x2.5 / 8.5x6.4
Shape	amorphous	amorphous	amorphous
Fracture	3-5	3-5	3-5
Porosity shape	mix	spherical	spherical
Porosity size (mm)	1-4	1-6	1-11
Porosity %	<10	<15	<10
Inclusions	FM	FM	FM
Vitrification	NA	NA	NA

The table is set up with the classification categories down the left hand column. In the case of Spit 5 the three most abundant dominant types by weight are FMT, corrugated, and glassy. The next category sets out their material type. The weights were taken with the samples clean and dry. As can be seen the difference in weight between the most represented, FMT at 14.23kg, and the least, glassy at 6.75kg, is 7.48kg. This shows the large difference in abundance over the highest three represented. The number of samples in each group follows a similar range with FMT comprising 296 samples and glassy 154.

The minimum and maximum size category show that there is not a large variation in the size of the fragments. This could be of interest showing a breaking of the material to a more manageable size or the natural fracture size of the specific material. The shape recorded across all these types was ’amorphous’, and this was common throughout the trench as samples were fractured to such a size that an overall shape of the intact artefact could not be estimated. All three types have the same fracture rate of between 3-5 edges. This could be an indicator of the way in which slag fractures.

Porosity was classified through three different categories shape, size and abundance via percentage of samples volume. The FMT has a mix of different shaped porosities whereas the corrugated and glassy just have spherical. This can help give an interpretation of the viscosity of the slag and the dynamics of its cooling. The porosity size varies with FMT having the smallest range from 1-4mm and the glassy having the largest of 1-11mm, almost three times larger. The porosity percentage is fairly similar with corrugated having the highest at <15% and FMT, and glassy both having <10%.

All three types have inclusions of furnace material. This could be of interest as it could show burnt clay was present outside of the furnace for the slag to flow onto. All three types are devoid of vitrified material therefore they are all recorded as NA.

7.4 Analysis of quantification and classification data

The analysis of the quantification and classification datasets will be set out in the first half of this section. The analysis will then be used to create interpretations of the processes and working practices present on the site and feed into the wider understanding of the site itself.

7.4.1 Weight of material

The weights of materials excavated from Standen trench 1 will be analysed in this section by size category and material type. These weights have been converted to percentage weights to standardise the data in order to investigate underlying trends.

Slag size category

TABLE 7.7: Percentage weight of Slag size categories by spit (kg)

Size	large		small		matrix		
Spit	weight	%wt	weight	%wt	weight	%wt	total %wt
1	46.18	15.08	38.42	12.55	9.63	3.15	30.78
3	53.25	17.89	17.24	5.79	12.71	4.27	27.95
5	54.13	20.15	50.56	18.82	9.42	3.51	42.47
7	41.40	20.01	32.72	15.81	7.47	3.61	39.43
9	13.86	18.95	3.07	4.20	3.20	4.38	27.52
total weight	208.82	NA	142.00	NA	42.44	NA	NA

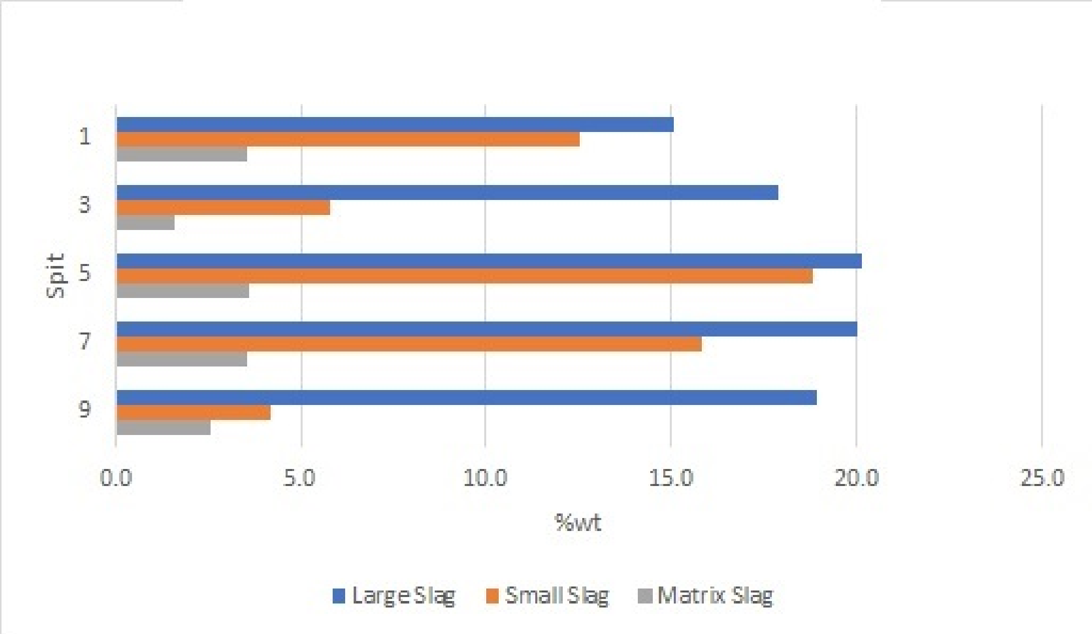


FIGURE 7.12: Percentage weight (%wt) of spit of Slag size categories, Standen

Of the slag, the largest component is the large size category, followed by the small and then matrix (Table.7.7, Figure 7.12). As stated earlier when analysing the slag from Chitcombe this distribution by size is to be expected. From the classification set out previously it has been seen that the technology being used on site is slag tapping. Due to this the slag on site is likely to exist in larger fragments.

The large category shows a gentle curving trend, gradually increasing from spit 1 to 5, before gently decreasing to 9. This curve keeps the representation of the large category with a 5%wt range. With no evident increases and decreases it could be interpreted that the slag is being produced in a continuous operation rather than in set periods of intense cyclical smelting.

The small category shows a wave trend, decreasing from spit 1 to 3, increasing to 5, then decreasing again to 9. The trends of the small and large categories do not match. Due to this it cannot be said for certain that the small category is necessarily formed by the fracturing of the large material, as suggested at Chitcombe, but rather may be formed by other action.

The matrix category has a shallow wave trend, decreasing from spit 1 to 3, and increasing to 5. The data then plateaus between spit 5 to 7, before decreasing to 9. These trends broadly mimic those of the small category. This can be interpreted to suggest the matrix slag is formed at the same time and the same action as the small category, possibly from fracturing during movement and re-deposition.

Furnace material size categories

TABLE 7.8: Percentage weight of furnace material size categories by spit (kg)

Size	large		small		matrix		
Spit	weight	%wt	weight	%wt	weight	%wt	total %wt
1	7.83	2.56	3.08	1.00	2.09	0.68	4.24
3	5.44	1.83	1.25	0.42	1.75	0.59	2.83
5	7.56	2.81	7.25	2.70	2.50	0.93	6.44
7	5.55	2.68	4.88	2.36	1.08	0.52	5.56
9	3.02	4.13	1.32	1.80	0.93	1.27	7.20
total weight	29.39	NA	17.77	NA	8.36	NA	NA

Of the furnace material the highest occurrence is the large category, followed by the small and then matrix (Table.7.8, Figure 7.13). As has been noted previously the order of occurrence of these size categories would be expected due to the large material tending to be well burnt or vitrified material, and having better structural integrity to survive in larger pieces. The small and matrix

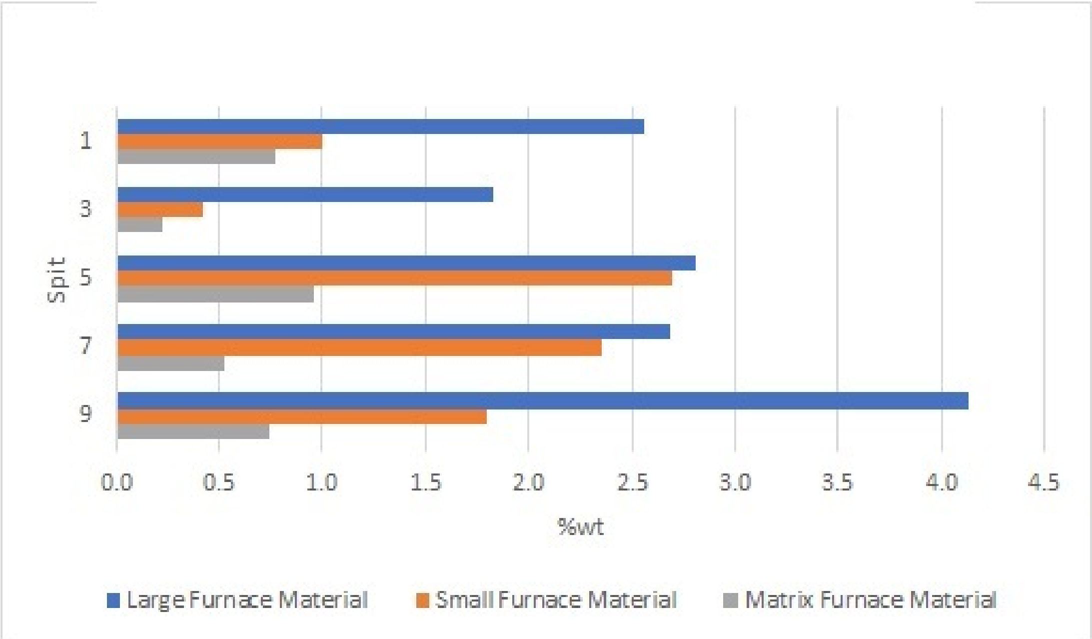


FIGURE 7.13: Percentage weight (%wt) of spit of furnace material size categories, Standen

material would be down to fracturing and breaking of the furnace material in repair of the furnace or deposition. Moreover, it must be noted that these size categories could have been enhanced in the data by the sieving method used to separate the size categories.

All three of the size categories show wave trends of increase and decrease. The large and matrix categories have the same trends decreasing from spit 1 to 3, increasing to 5, decreasing to 7 and increasing to 9. The small category also matches the large and matrix from spit 1 to 7, but decreases from 7 to 9. It can be said with a level of confidence that, due to the similarity in trends, all the furnace material size categories are being produced in the same processes or at a standard rate through fracturing during movement and/or deposition. The rhythmical wave trend could be indicative of a cyclical process creating higher and lower abundances in the technological waste deposit. Care must be taken with this conclusion due to the processes of deposition which will be discussed in more detail in Chapter 10.

Geological size categories

TABLE 7.9: Percentage weight of geological size categories by spit (kg)

Size	large		small		matrix		
Spit	weight	%wt	weight	%wt	weight	%wt	total %wt
1	0.33	0.11	0.93	0.30	3.98	1.30	1.71
3	0.77	0.26	0.59	0.20	6.58	2.21	2.66
5	0.20	0.07	1.79	0.67	2.80	1.04	1.78
7	0.50	0.24	1.41	0.68	3.49	1.69	2.61
9	0.00	0.00	0.25	0.34	1.03	1.41	1.75
total weight	1.80	NA	4.95	NA	17878	NA	NA

Of the geological material size categories (Table.7.9, Figure 7.14) the largest group is the matrix category. Next is the small category, which has the second highest representation across spits 1, and 5 to 9, becoming least abundant in spit 3. The large category has the lowest representation across spits 1, and 5 to 9, but increases in spit 3.

As has been stated previously at Chitcombe, it is interesting that the abundance of geological material is the reverse of the occurrence of slag and furnace material. This is not believed to be due to larger geological material being broken during or after deposition, but rather a true reflection of the abundance of the material. It is also not believed that the method of sieving has created smaller and matrix groups as the geological material is stable enough to withstand the mechanical movement of sieving. This then shows a process

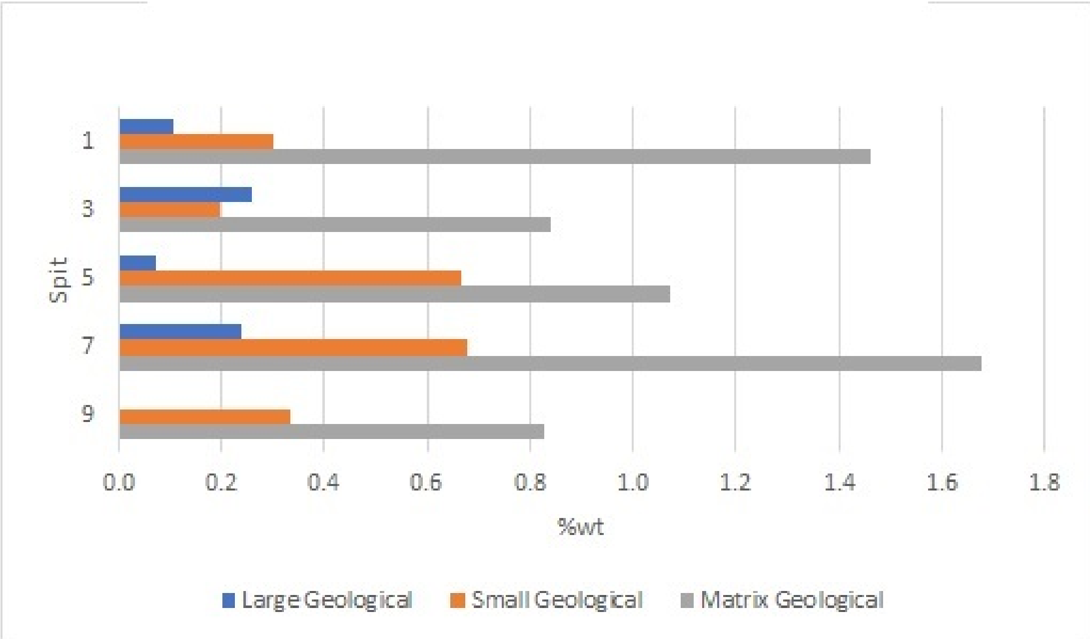


FIGURE 7.14: Percentage weight (%wt) of spit of geological size categories, Standen

occurring elsewhere, either on or off site that is producing geological material between 50μ to 6mm in varying quantities. This is possibly from the crushing and processing of ore.

All of the size categories have wave trends in their occurrence. The trend of the large categories is alternating increase and decrease. This could be interpreted as indicating a cyclical process. However, with such a low presence within the trench as a whole and only having a range of 0.2%wt this could be seen as insignificant.

The small category also shows a broad wave trend, decreasing from spit 1 to 3, increasing to 5, with a plateau between 5 and 7, before decreasing to 9. These trends oppose those of the large category, showing the production is not due to fracturing during deposition.

TABLE 7.10: Percentage weight of materials by spit (kg)

Size	FR		slag		fm		geo		
Spit	weight	%wt	weight	%wt	weight	%wt	weight	%wt	T %wt
1	193.74	63.27	94.24	30.78	13.00	4.24	5.23	1.71	100
3	198.14	66.56	83.19	27.95	8.44	2.83	7.93	2.66	100
5	132.49	49.31	114.11	42.47	17.32	6.44	4.78	1.78	100
7	108.40	52.39	81.58	39.43	11.51	5.56	5.40	2.61	100
9	46.47	63.53	20.13	27.52	5.27	7.20	1.28	1.75	100
TW	679.24	NA	393.26	NA	55.53	NA	24.63	NA	NA

TW = total weight of material, T%wt = total percentage weight per spit

The matrix also shows a wave trend, decreasing from 1 to 3, increasing to 7, before decreasing to 9. This trend could be indicative of a cyclical process producing more and less of the matrix geological material. This is most likely to be ore fines either associated with the processing of the ore or cleaning out of the furnace.

The low occurrence of all geological material within the trench could be interpreted as showing the value of the material with only a small amount of it being discarded. It could also show the skill of the smelters in identifying the appropriate ore for smelting, and processing this off site.

<u>All materials</u>

By comparing the patterns of increase and decrease it is possible to associate materials with matching patterns which may infer production and deposition actions.

There are three pairs of matching trends across the material size categories. The first is the large and matrix furnace material, which can be explained by breakage during movement, deposition, and taphonomic processes. The next is small slag and small furnace material. An explanation for these types and sizes having matching trends is their potential creation in the emptying and clearing of the furnace which could cause the fracture of slag and furnace itself to produce the smaller size category. The third pair is the matrix slag and small geological. There is no clear causation for the trends of these two categories being the same so this can be attributed simply to a coincidence of correlation.

To understand further any trends in the material it has to be looked at by merging the size categories. This can be seen in Table 7.10 and Figure 7.15.

The clearest opposing of trends is between the slag and fine residue. This can be simply explained by both of them dominating the representation by %wt in the spit, with the furnace material and geological being very low in their representation. It must therefore go that when one dominant material decreases, the other must increase to keep the %wt equalling 100%. The trend of the increase and decrease in the %wt of Slag could be indicative of periods of more and less smelting intensity, or the organisation of processes such as smelting and the repairing or renewing the furnace.

As previously mentioned if a cyclical process of smelting were to occur on a site, then it would be expected in the data to see that when the amount of one increases the other decreases and vice versa. When comparing the data it can be seen that the slag and furnace material have the same trends from spit 1 to 7, only opposing in spit 9. This then does not fit the standard idea of opposing deposition. There are a number of discussion points as to why this might be, including intensity of smelting and post-deposition taphonomic processes.

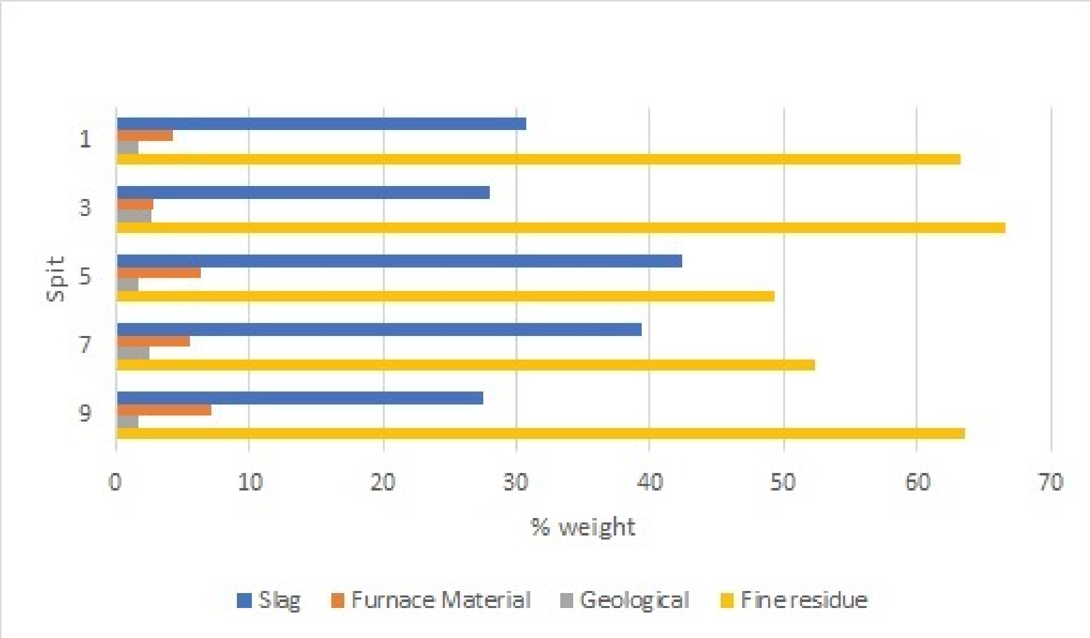
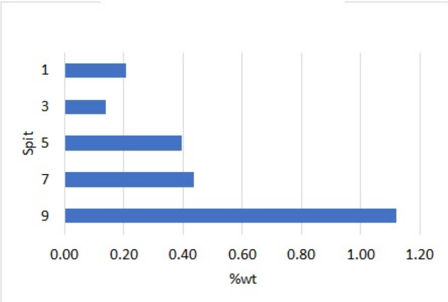


FIGURE 7.15: Material as percentage weight of spit

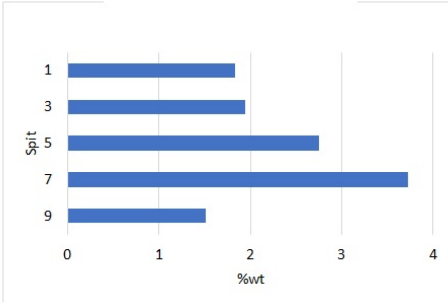
7.4.2 Classification of technological waste

The classification of the material from Standen followed the same steps as for Chitcombe. Again, the types identified as being important for the aims of this project are those which are represented in over half the spits. At Standen these include seven types which are present in all five of the spits; burnt clay, corrugated, fluid movement tendril, furnace slag, glassy, magnetic, and vitrified mixed furnace material. There are then five types which are present in four of the spits, all of which are in consecutive spits. These types include, dense surface, light porous, messy ripple, porous surface, and sandstone. Only one type is represented in three spits, which is smooth (ap D.4.1).

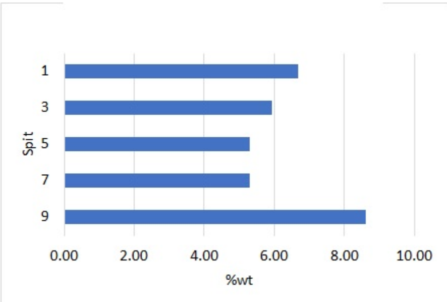
To understand the dominant types they have been plotted on individual graphs (fig.7.16 and 7.17).



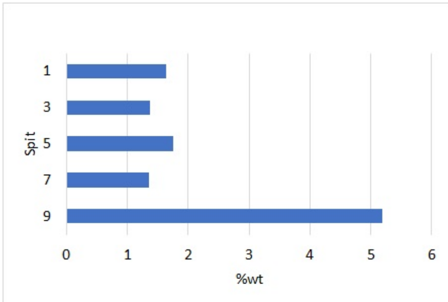
(A) %wt of Burnt Clay, Standen



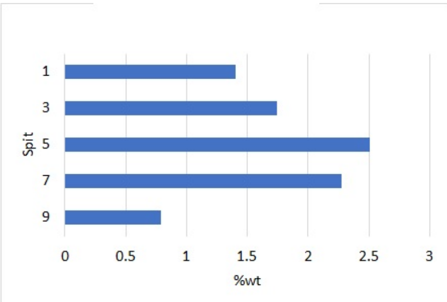
(B) %wt of corrugated, Standen



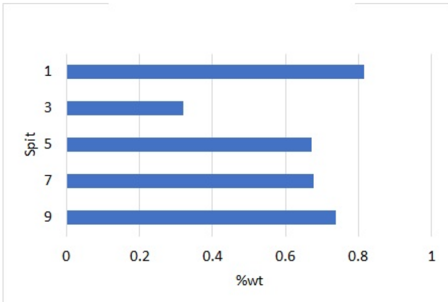
(C) %wt of Fluid Movement Tendril, Standen



(D) %wt of Furnace Slag, Standen

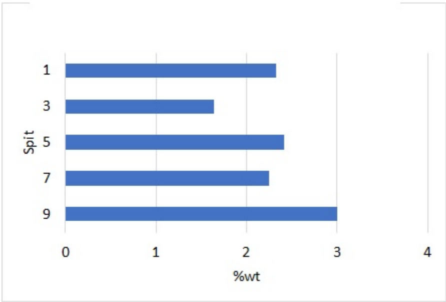


(E) %wt of Glassy, Standen

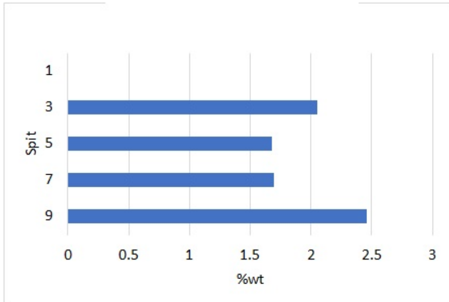


(F) %wt of Magnetic Slag, Standen

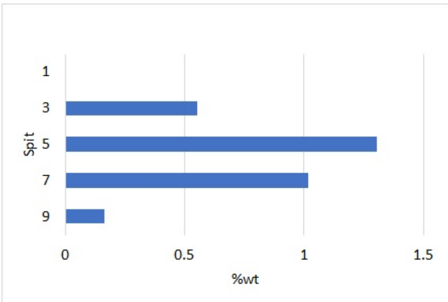
FIGURE 7.16: Graphs depicting % weight of individual types of the initial spit weight, Standen [1]



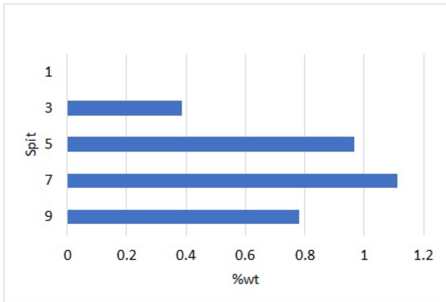
(A) %wt of Vitrified furnace material, Standen



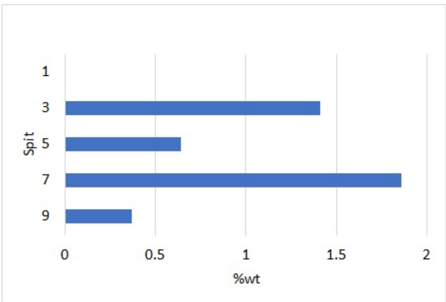
(B) %wt of Dense Surface, Standen



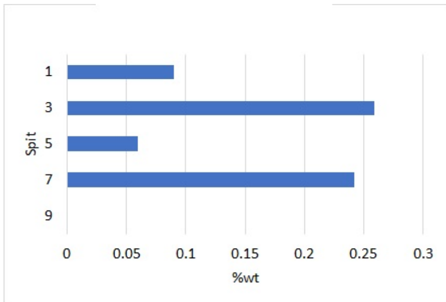
(C) %wt of Light Porous, Standen



(D) %wt of Messy Ripple, Standen



(E) %wt of Porous Surface, Standen



(F) %wt of Sandstone, Standen

FIGURE 7.17: Graphs depicting % weight of individual types of the initial spit weight, Standen [2]

When comparing the trends of all the types it can be seen that there are groups with similar increases and decreases across the trench. Two types that match in their trends are furnace slag (fig 7.16d) and vitrified furnace(fig 7.17a), both of which decrease, increase, decrease then increase. A logical reason for this match in trends can be reached by the fact that both of these types are created within the furnace, but can only be removed by human action. This match in trend would therefore show that these two types are both being removed from the furnace and discarded at the same time in a potential cyclical process.

A further two types that match in their trends are porous surface (fig 7.17e) and sandstone (fig 7.17f) both of which increase, decrease, increase then decrease. It is difficult to come to an interpretation as to why these two types share the same trends. With no clear reason how they could be connected there are two potential interpretations, the first being the processes occurring that lead to the deposition of these materials are occurring at the same time and are only connected in as much as they result from processes occurring on site. The second is that it is mere coincidence. The two groups just discussed oppose each other in their occurrence meaning that when one increases the other decreases and vice versa. This shows that whatever processes are producing the porous surface and sandstone types have a potential cyclical pattern that is syncopated with the cyclical process producing the furnace slag and vitrified furnace material.

The types glassy (fig 7.16e) and light porous (fig 7.17c) also both have matching trends. The fact that these two types have matching trends could help to give a better interpretation of the technology and techniques being used on the site, potentially indicating a higher temperature and/or higher reducing furnace.

These two types are opposed in their trends by the fluid movement tendril group (fig 7.16c), potentially showing that a different process is being used to produce the lighter and glassy material rather than the more common tap slag.

The three types, burnt clay (fig 7.16a), magnetic slag (fig 7.16f) and dense surface (fig 7.17b) also match in their trends. The burnt clay and magnetic slag are both types that would probably be removed from the furnace through human action at the end of the smelting process. The fact that dense surface has the same trend as these two other types could suggest that there is a process of breaking slag into smaller, more manageable pieces for removal to the waste deposit which would have occurred at the same time the furnace material and magnetic slag is being removed from the furnace. Further types that match in their trends are the corrugated (fig 7.16b) and messy ripple (fig 7.17d). Both these types indicate some form of movement in the slag but do not have the classic indicator of tendrils. With similar trends it could be interpreted that that these types are being created at a similar point in the process and differ due to minor viscosity variations of the heterogeneous slag. However, care must be taken here as there is no occurrence of messy ripple in spit 1 whereas there is corrugated present. Therefore, it cannot be said for certain that these types are connected.

While the large material from within each spit has been classified into a number of different types, a number of these can be joined together to form larger groups which can inform more closely on the organisation of processes on the site.

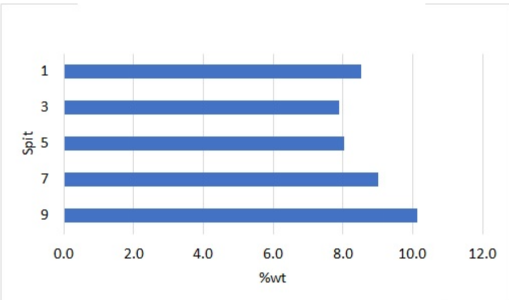
As with Chitcombe, types that indicate fluidity or movement of the slag can be grouped together. The type 'corrugated' can be used as a proxy to fluid movement along with the obvious group 'fluid movement tendril'. It was decided not to include messy ripple in this group as it is not represented in all five spits and therefore could not be guaranteed to be created in the same process as the fluid movement tendril and corrugated groups. These two types, when combined, give a better understanding of when the most intense periods of smelting might be occurring. Looking at the data for this combined Movement group (Fig: 7.18a) across the spits it can be seen that there is very little fluctuation in the data. The presence decreases slightly from spit 1 to 3 before increasing from spit 3 to 9. This shows a potential increase in intensity of smelting around spit seven and nine. However, the fluctuation in data is 2.25%wt ranging from 10.13%wt to 7.88%wt. So, although there is an increase it is small so the increase in intensity could also be small.

There are a number of other types that have been identified and described which can be seen as representative of material formed within the furnace that could have only been removed through human action. This includes 'furnace slag', 'magnetic slag', 'dense slag', 'possible furnace', and 'furnace cake fragment'. When all these types are combined, given the group type In Furnace, and shown on a graph as a percentage weight of the entire spit (Fig: 7.18b), it can be seen that there is a slight fluctuation across spits 1 to 7. There is then a sharper increase from spit 7 to 9. The fluctuation across spits 1 to 7 is insignificant, fluctuating by only 0.36%wt. The increase from spit 7 to 9 is around 4%wt and could represent a time of more intense cleaning of the furnace.

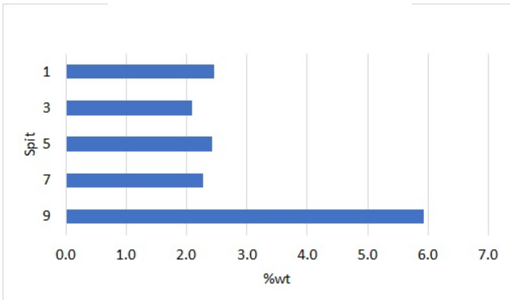
There are a number of types formed of furnace materials including 'burnt clay', 'vitrified mixed furnace material', and 'possible furnace lining'. Rather than join the 'burnt clay' and 'vitrified mixed furnace material' as has been done with other groupings these have been kept separate as they may represent slightly different processes. When the data for the 'burnt clay' is plotted on a graph (Fig: 7.16a) it can be seen there is a decrease from spit 1 to 3, and then increase from spit 3 to 9. This increase is not linear. The increase from spit 3 to 5 is 0.26%wt, the increase from spit 5 to 7 is 0.04%wt, and the increase from spit 7 to 9 is 0.69%wt. With the decrease from spit 1 to 3 this causes the appearance of fluctuation. When the percentage weight of the 'vitrified mixed furnace material' is plotted on a graph (Fig: 7.17a) it can be seen there is a decrease from spit 1 to 3, it then increases to spit 5, decreases to spit 7 and then increases to spit 9. Although there is a decrease between 5 and 7 the overall trend across spit 3 to 9 is overall increase. Both of these types so an overall trend of decrease from 1 to 3 then overall increase through to 9, showing the intensity of production of both these types is very similar.

When all these groups are compared it can be seen that the slag that represents tapping, the slag that represents material formed and removed from the furnace, and furnace material all show a trend of increase with the highest percentage weight around spit 9. The trend of increase and decrease in intensity also matches across the internal furnace material and both types of furnace material showing all three of these types are linked. This then shows that the cleaning and repair of the furnace occurs at the same time.

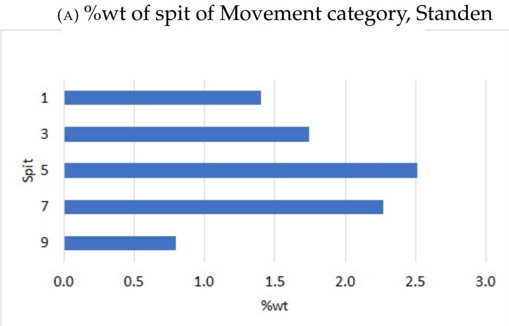
Another type that stands out as being distinct at Standen is the 'glassy slag' and 'messy ripple', which occasionally contained glassy material. When the 'glassy slag' is plotted on a graph (Fig: 7.16e) it increases from spit 1 to 5 with spit 3 to 5 being slightly steeper. It then decreases from spit 5 to 9 with a shallower decrease from spit 5 to 7 then a sharp decrease from spit 7 to 9. When the 'messy ripple' is plotted on the graph (Fig: 7.17d) there is an increase from spit one to seven with three to five being slightly steeper that one to three and five to seven being very shallow. It then decreases sharply from seven to nine. When these are compared it can be seen that both types follow a very similar trend of an overall increase and decrease, only differing slightly between spit five and seven. The correlation in the overall trend in these materials shows that they are potentially connected in their production, possibly pointing to a specific process.



(A) %wt of spit of Movement category, Standen



(B) %wt of spit of In Furnace category, Standen



(C) %wt of spit of Messy Glass category, Standen

FIGURE 7.18: Graphs depicting group categories as percentage weight of the spit, Standen

When the trends of the ’glassy’ and ’messy ripple’ types, combined into a group type called Messy Glass (Fig: 7.18c), are compared to the furnace material (Fig: 7.16a, 7.17a), In Furnace (Fig: 7.18b), and Movement (Fig: 7.18a) groups it can been seen that the trends do not match. An example of this is that all the groups have a trend of increase to spit 9 whereas the messy glass decreases to spit 9. The Movement group forms the overall shape of a shallow ’U’ shaped curve, whereas the messy glass group forms an ’n’ shape, showing an opposition in the production of these two materials. When compared to the internal furnace and furnace material groups, which both match in their fluctuating trends, it can be seen again that these groups do not match in their trends. A couple of plausible explanations for the opposing trends between the movement group and the glassy group revolve around processes and working practice. The first is that both groups are formed in different processes and the opposing trends are merely coincidence. The second, and more plausible, is that a working process is occurring which alters the chemistry in the furnace which changes the type of slag being produced from what would been seen as a standard slag to a highly siliceous glassy slag. This would explain the trend of when one is more prevalent in the spit the other is less.

There has been no discussion throughout this chapter comparing the weights or classification of spit material with its contexts. The reason for this, as can be seen in figure 7.6 is that there were no really clearly defined contexts within Standen. The reason for this is believed to be due to the rate of deposition and the possible vegetation cover of the site over time. So, although this causes a lack of understanding it shows the strength and validity of using the spit excavation technique to give an understanding of change in material throughout the depth of the deposit, which would have become mixed and lost if only relying on context excavation.

7.5 Discussion

This section will discuss all the data presented throughout this chapter putting it in context with reference to the site. A discussion will then be had placing Standen into a landscape setting.

7.5.1 Excavation

Throughout the excavation of T1 no dating evidence was found. This means the 'boundary bank' which was described by Straker is still of an unknown date. While excavating, no evident stratigraphy could be seen within the technical waste deposit. This lack of stratigraphic detail is not seen as evidence that It is also not believed that the deposit below the level of the bank has been disturbed and is therefore still in situ. This may show that smelting on this site was undertaken on a small scale meaning large obvious deposits could not build up in the waste deposit. It could also show that the waste deposit built up over a long period of time allowing for a fairly even build-up of matrix within the layers from the likes of leaf litter and hill wash distorting any evident deposit layer.

Trench 2 shows only shallow technological waste depth. Being such a distance down the ghyll side from the boundary bank it can be said with a high level of certainty that this area has not been affected by ploughing, therefore all material is still in situ. The position of the trench and the shallowness of deposit on the western side of the trench also ground truths the magnetometer survey showing the curve heading from the southeast of the survey to the north is a good representation of the edge of the technological waste deposit

Trench 3 showed a significantly higher number of finds in the trench that were not technological waste from iron production, covering dates from the Roman to Victorian. However, these finds were mixed throughout the extent of the trench. The only explanation for this is that the deposit has been completely affected by ploughing. This trench was excavated within woodland, however with such evident plough mixing this area must have at some point been under the field, most likely up to a time where stronger ploughs were used, evident by the depth of ploughing and the material ploughed through. At the base of T3, set within the natural, was a large amount of vitrified furnace material which looked to be in-situ and forming a feature. This could possibly be the remains of an earlier iron smelting furnace which became covered by technological debris. Due to only a small section being uncovered and a lack of time and resources it was decided not to investigate this feature further, so it can be excavated properly at a later date.

7.5.2 Post-excavation analysis

Looking at the morphological analysis of the technological debris it can be seen that the main technology being used on this site was slag tapping. This is because across all spits fluid movement tendrils were the highest represented with a large amount of corrugated which is a proxy for fluid movement. Moreover, a single 'foot' was discovered in T1 which is evidence that the slag has flowed out of the furnace from a height.

Another highly represented sample group was glassy slag. This type was associated with a number of different textures including fluid tendrils, corrugated and messy ripple which may be another proxy for tapping. However, fluid movement has more of an impression of being artificially moved so may come from within the furnace. This glassy material has been interpreted as a very high silicate slag possibly formed by higher furnace temperatures or greater reducing conditions. With a large amount of vitrified furnace material evident this may help with the interpretation of a higher temperature furnace. This siliceous slag could also have been formed due to fluxing.

The technological debris shows a high level of fracturing with sharp edges still preserved. This could represent a working practice in which the waste is methodically broken to make it easier to move from the smelting area to the waste deposit. It also shows that material has not been exposed to the elements for a long period of time or repeatedly redeposited.

A specific type of material was discovered which has been interpreted as furnace lining as it was different to the clay found that was baked and assumed to form the main body of the furnace. It also formed a curve as if it had broken clean from the inside wall. This could represent another working practice of relining the furnace for longer use of the main structure.

When looking at the overall constituent weights of the spits of T1 analysed it can be seen that the most common material by weight is fine residue smaller than 50μ followed by slag, furnace material and the least frequent geological. When this is calculated into percentages by weight of materials throughout each spit and averaged then it shows us that 59.0%wt is fine residue, 33.6%wt is slag, 5.3%wt is furnace material and 2.1%wt geological.

As seen in chapter 5 a intensity factor can be calculated by looking at the ratio of furnace material to slag present on a site. In Standen trench 1 furnace material represents 55.53kg and slag 393.26kg which gives a ratio of 1 : 7.08 which gives 14.12%.

7.6 Site interpretation

In the initial investigation of the site by Straker and Mason (1939) it was said that the depth of the deposit was 12 to 15 inches (30-38cm). After the investigation of this site it can be seen that this measurement is slightly lower than now recorded. This may be explained by the different locations of excavated trenches. The three trenches excavated in this project get deeper towards the boundary ditch and then become shallower again going down the hill towards the ghyll. Therefore, it may be extrapolated that the depth of slag decreases the further you go from this deep point along the boundary ditch, meaning that where Straker excavated further into the field his depth measurement would fit with data from this project. The boundary bank is positioned along the precipice of the ghyll-side which could also play a role in the depth of deposit at this point.

The slag that was excavated and analysed during this investigation shows a large range of morphologies. However, when looking at distribution it can be seen that the majority of slag is evidence of fluid slag being removed from the furnace by tapping. There is also a large amount of slag that is highly fractured to the point it has no identifying features. If the number of types of slag identified was an indicator of consistency of smelting it may be said that there was inconsistency on this site. However, when distribution is taken into account and a broader view it could be said that this site is smelting consistently. Also, the glassy slay was found throughout the extent of the waste deposit meaning this material was being created at each smelt also showing a consistency in process.

The pottery discovered on this site gives dates from early to mid-first century AD to late second to early-fourth century AD. The piece found in T3 which has the earliest date has to be taken with caution. It was discovered at the base of the waste deposit on the natural. This means there is a chance that this piece of pottery pre-dates the waste deposit. The two pieces that were discovered in T3 show dates of second to early third century AD and post AD 270. These dates must also be taken with caution as in the same levels a late 17^{th} century tobacco pipe stem was found as well as Victorian pottery. That means this Roman date pottery may have been mixed from a different layer into the waste deposit. It is believed though that this is probably not the case and the site dates to somewhere in the second century AD onwards. The fragment of Romano-British tile could indicate the possibility of some sort of structure in the vicinity.

The preservation of this site is greatly variable. It can be seen from the excavation that the land to the east of the boundary bank has been ploughed at some point, mixing the material, seen in the spread of material in T3. This means the chances of good preservation of such features as furnaces is very low and if modern ploughing were to restart there is a chance evidence could be lost forever. Part of this area to the east of the boundary bank is now in woodland on National Trust land and as such stands a better chance of future preservation. The waste deposit at the boundary bank and west down into the ghyll does not seem to have been affected by ploughing, as can be seen in T1 and T2. However, that does not mean this area is safe from destruction. There are a large number of established trees in this area with smaller trees establishing. The roots from these trees have as much potential, if not greater, to cause damage to the waste deposit and any features that could be preserved beneath it, for example the potential furnace in T3.

In conclusion, this study has showed that there is great potential in the use of a multi-faceted approach of geophysical surveys and excavation to inform on the organisation and current preservation of these sites. It shows Standen has the potential for the remains of furnaces linked to the waste deposits still being partially in-situ along with a large portion of the waste deposit itself.

From this project it would be recommended that a larger scale project is undertaken on this site with further geo-prospection surveys and excavation focusing on continued ground truthing of geo-prospection responses of waste deposits and excavations of the possible furnaces to understand the technology being utilised. Further excavation would also help in creating a more statistically strong slag%wt which this project has calculated as 32.7%, 17.3% lower than the 0.5 correction factor used when estimating the size of the Roman iron industry of the Weald.

8 Analysis of Geo-prospection data

8.1 Introduction

Having set out the field strategies, dataset collection and results for the two case studies in the preceding chapters, the aim of this chapter is to take a closer look at the performance of the various techniques used during the geo-prospection surveys and assess their effectiveness as tools for investigating metallurgical sites. This will be done by comparing the datasets from both case studies that cover four key feature types. By reviewing the geo-prospection results both in the light of subsequent insights from excavation and across the two sites, it will be possible to make a more nuanced judgement of the value of these techniques. Some of the figures used in this chapter are repeated elsewhere in the thesis and they are used here for ease of illustration.

8.2 Key feature analysis

The first three of the four key features selected for further analysis are those which play central roles in the formation of iron production sites, namely technological waste deposits, furnaces and working areas. The fourth key feature, ditches, have wider archaeological occurrence and are relevant in the context of the Chitcombe and Standen case studies.

8.2.1 Technological Waste Deposit

Technological waste deposits (TWD) are one of the most important features on an iron production site. They help to identify the scale of production on a site, and contain information on the specific processes of production occurring on the site, along with any changes or variation over time. TWD will be analysed in more detail here with reference to the different geo-prospection surveys used across both case studies, along with discussion on the areas that do not represent the technological waste deposit but are formed of technological waste, as seen in Chitcombe trenches 1, 2, and 13. This comparison is important as it is the same material in both but representing different forms of deposition, and being able to discern between the two is important. The focus on the TWD for this discussion will be along the northern edge of Chitcombe, particularly, field 2 and throughout the woodland at Standen. Both of these TWD have been confirmed through excavation as seen in both the trenches analysed for this project in chapters 5 and 7.

Magnetometry

Along the northern edge of both field 1 and 2 at Chitcombe is a large expanse of mixed magnetic response encompassing the excavated trenches 1, 2, and 14 which has been interpreted as a mixture of primary and secondary deposits (fig.8.1). The primary deposit, which represents the TWD is confined to a smaller area on the northern edge of the furnace workshops. The response

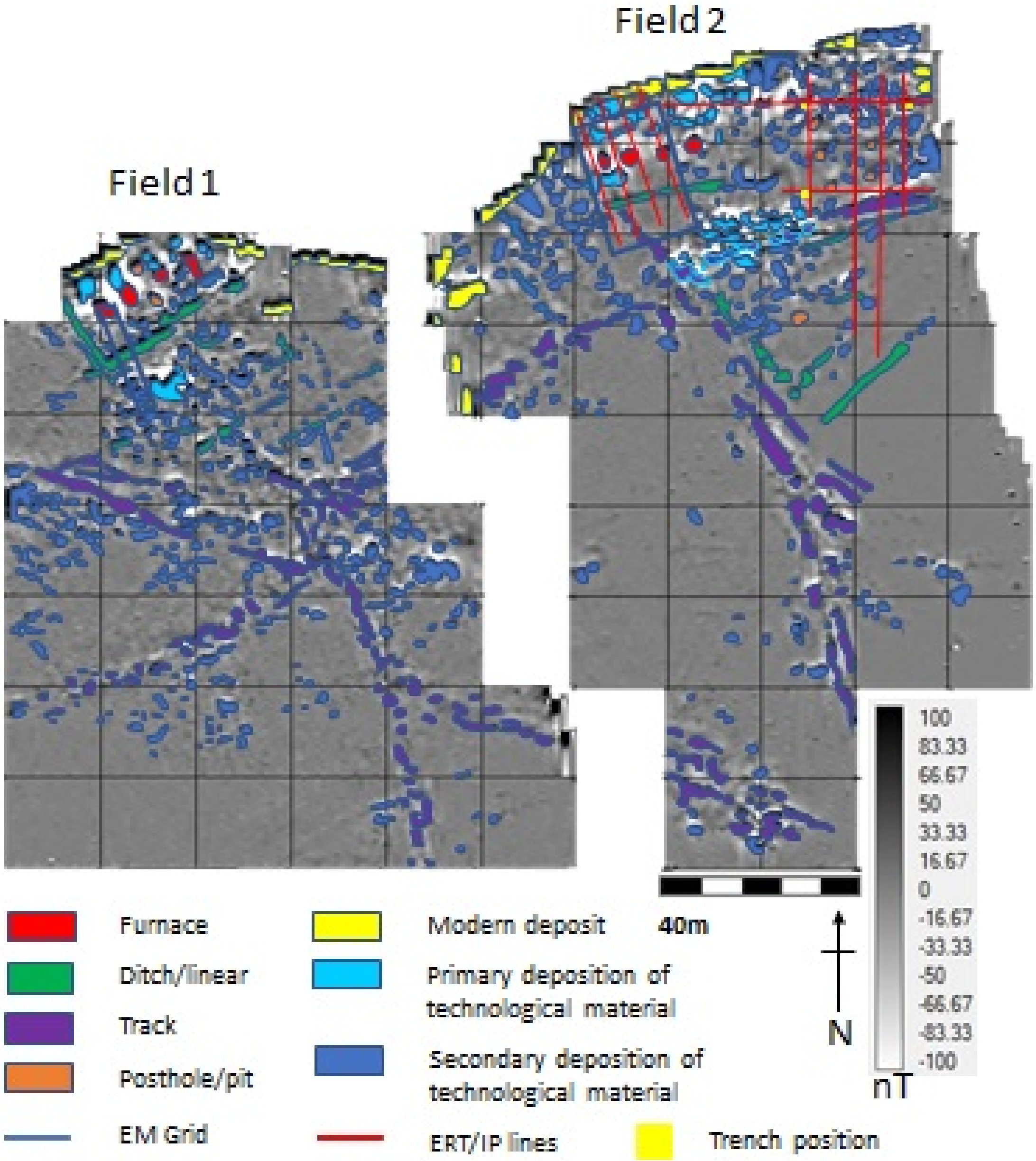


FIGURE 8.1: Interpretation overlay of Chitcombe magnetometer survey

from these areas ranges from around -300nT up to 1000nT. This response is what would be expected from a TWD as the material forming the TWD is extremely heterogeneous and contains large quantities of magnetic material. The initial difficulty with the interpretation of the northern end of field 1 is that the response from the primary and secondary deposits is very similar to magnetometry, even-though it was seen during excavations that the deposit changes from a coherent TWD to a general spread of material resembling a gravelled surface (ap B.2). This same problem is mimicked with the response from the trackways on site which is clearly seen in field 1 (purple), as mixed magnetism. The interpretation here is easier due to the locality.

From excavations at Standen the TWD is known to exist to a depth of 1.2m within the woodland part of the site (chapter 7.2). In the magnetometer survey this area is represented by a mixed magnetic response ranging from -600nT to 250nT (fig.8.2). The field bank that runs through the survey shows as a solid linear increased magnetic anomaly. The three trenches excavated show the difference in the TWD on this site with T1 and T3 being in areas with similar magnetic response but showing a vast difference in the material and depth of deposit. T2 was based on the edge of the magnetic response and shows the edge of the TWD. The working area on this site, which will be discussed in more detail later, also has the same response as the technological waste deposit, causing possible ambiguities with interpretation. However, by creating the categories of primary and secondary deposition a designation could take place along the field boundary, which is clearly identifiable, as all material to the east into the field would have been disturbed by ploughing.

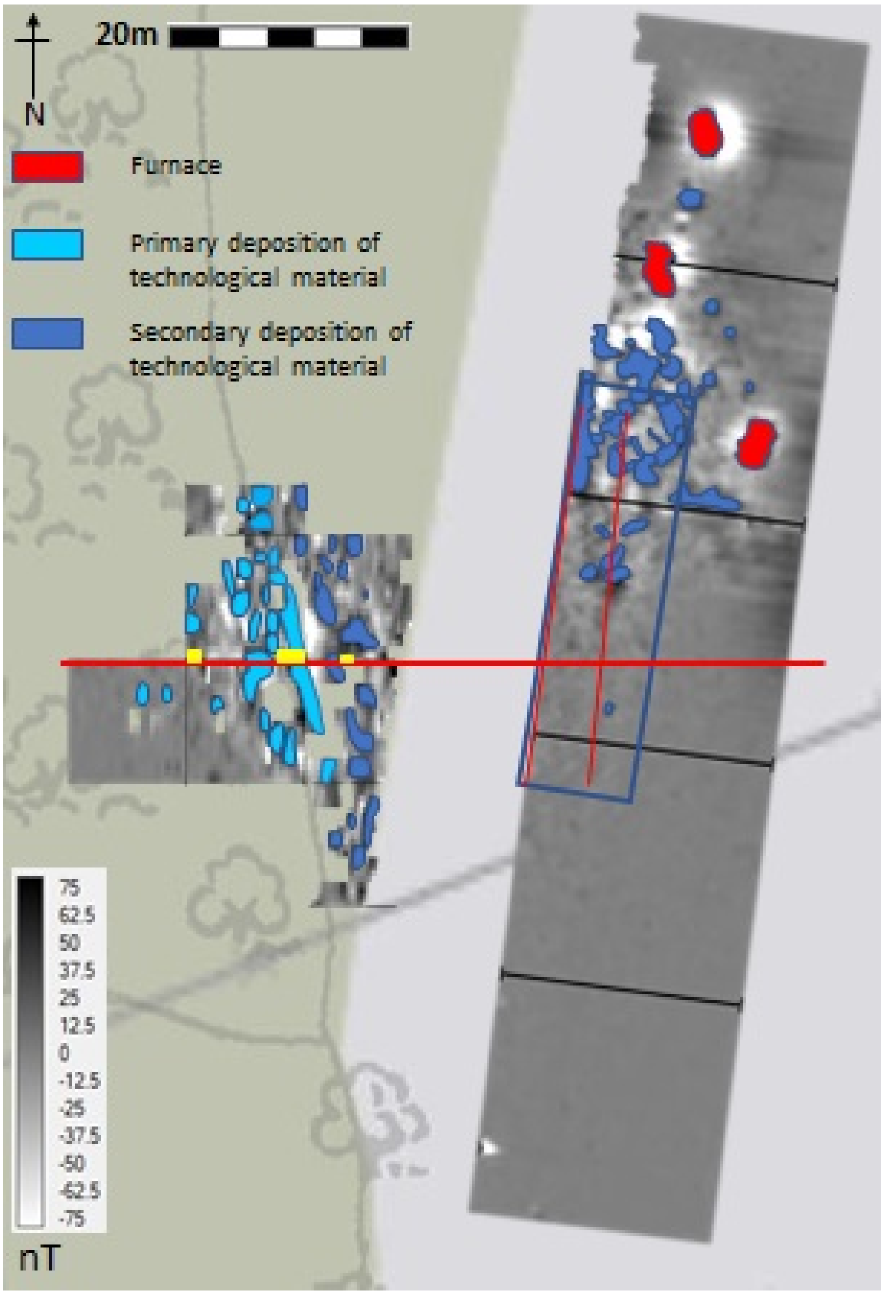


FIGURE 8.2: Interpretation overlay of Standen magnetometer survey

Looking at the responses from the magnetometry surveys across both case studies it can be seen that there are potential issues when using this technique to identify a TWD. The 'waste' material created when smelting, is purposefully utilised or accidentally moved around the site, and not discarded into a discrete TWD. The response of this material to the magnetometry survey is therefore not confined to a TWD but rather spread across a number of features within the site.

It can be seen that the interpretation is in some ways easier at Standen due to the fact that the site is smaller with fewer features, whereas at Chitcombe the technological waste material has been used for varying reasons and purposes over large areas around the TWD making interpretation more difficult. The fact the waste material is used over the site has further repercussions for other aspects of site interpretation.

Earth Resistivity Tomography

At Chitcombe ERT Lines 10, 11, 12, and 13 all contain a section of the TWD positioned on the northern edge of the smelting workshop in field 2 (fig. 8.1). In all these lines the TWD is represented by the light blue category in the interpretation overlay (fig.8.3). Throughout these four lines the upper reading varies between 230-300 Ωm. These high readings do not represent the whole waste heap but rather define discrete areas within the deposit which have a variety of readings. Much of the greater area of the TWD seems to have readings of 150 Ωm with the higher readings as mentioned and occasionally lower readings as can be seen in line 10 (fig.8.3). This shows that the TWD's do not react in a homogeneous way to this survey type. As seen in T14 (chapter 5, ap B.2.1), the various contexts would lead to very different responses to resistivity, with areas of increased slag and large voids (context 1403) creating a higher resistivity than areas high in matrix and moisture that was observed during excavation in the lower contexts of T14. The TWD is also seen in line 4 (fig A.42) as a high resistivity anomaly, similar to lines 10-13. However, the physical size of this response should be taken with caution as this is one of the 64m lines which gives a lower resolution, and can change the size of anomalies.

At Standen the entire width and depth of the TWD has been covered in Line 1 (fig.8.4), again being represented as the light blue category. This has a highest reading of 140 Ωm with the more general area measuring above 50 Ωm. It can be seen clearly that the TWD forms a large feature containing a number of anomalies that becomes thinner along the ground surface down the hill.

It can be seen that the TWD reacts differently between the sites. It is known that these types of deposit are heterogeneous so would not be expected to show a uniform response. However, the results shows that the lower end of resistivity in Chitcombe's TWD is as the higher end of Standen's.

The reason for this difference in response is believed to be due to the fine residue, which is material below 50μ and mostly formed of soil, rather than differences in the technological waste. This fine residue is more likely to infill the gaps around fragments of technological waste. As set out in sections 5.3 and 7.3 Standen has a much higher proportion of pure matrix than Chitcombe which would cause a lowering of the resistivity. There were also contexts at Chitcombe that contained a very large percentage of slag with voids between which would cause areas of increase to the resistivity.

When looking at the general levels of response of the TWD's to the ERT surveys in both case studies, it can be seen that they are not distinct or exclusive, with similar readings seen across other features and areas and represented by the primary undifferentiated archaeological deposits (UAD). This shows a potential issue with interpreting iron production sites from the ERT data, or even a single survey type, alone. As it is the technological waste that is reacting to the ERT survey, features can be misinterpreted as they all contain the same material.

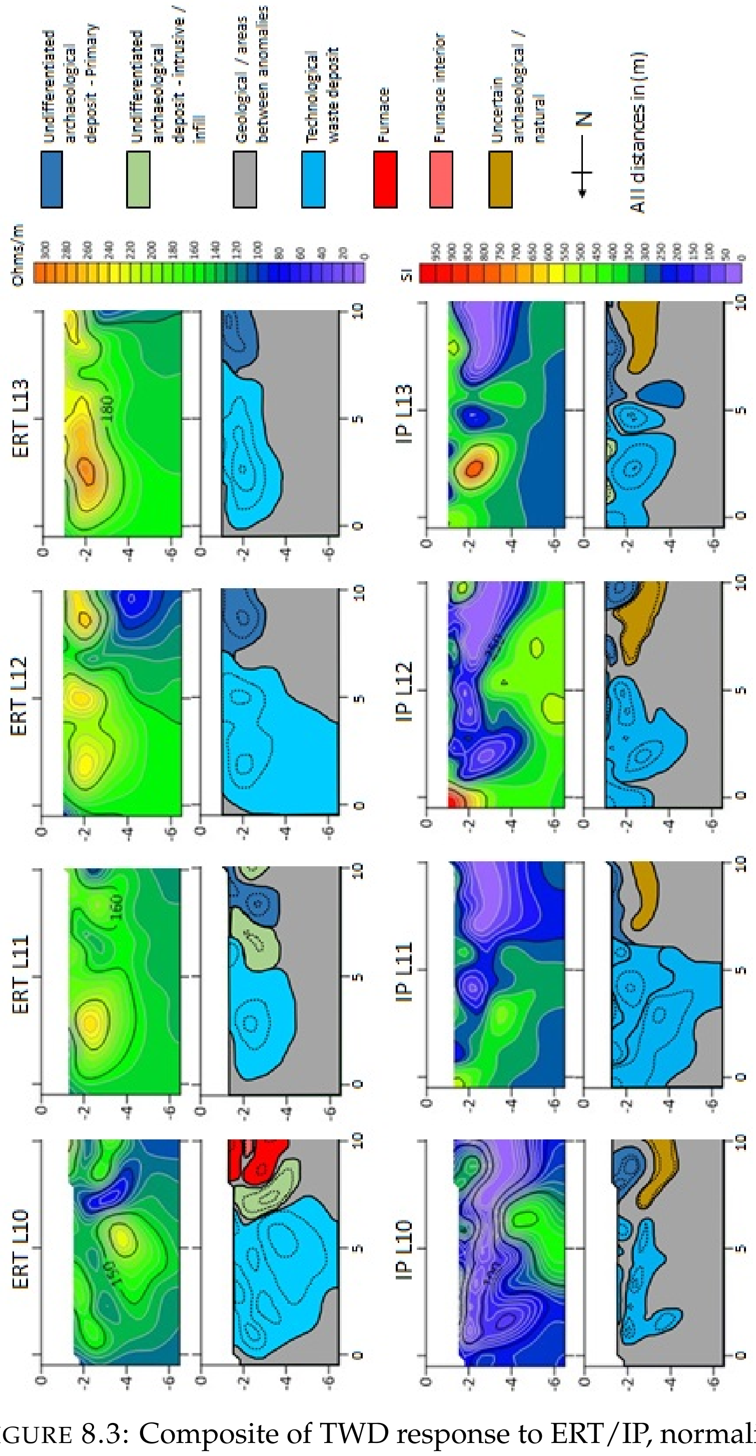


FIGURE 8.3: Composite of TWD response to ERT/IP, normalised and interpreted, Chitcombe L10-13

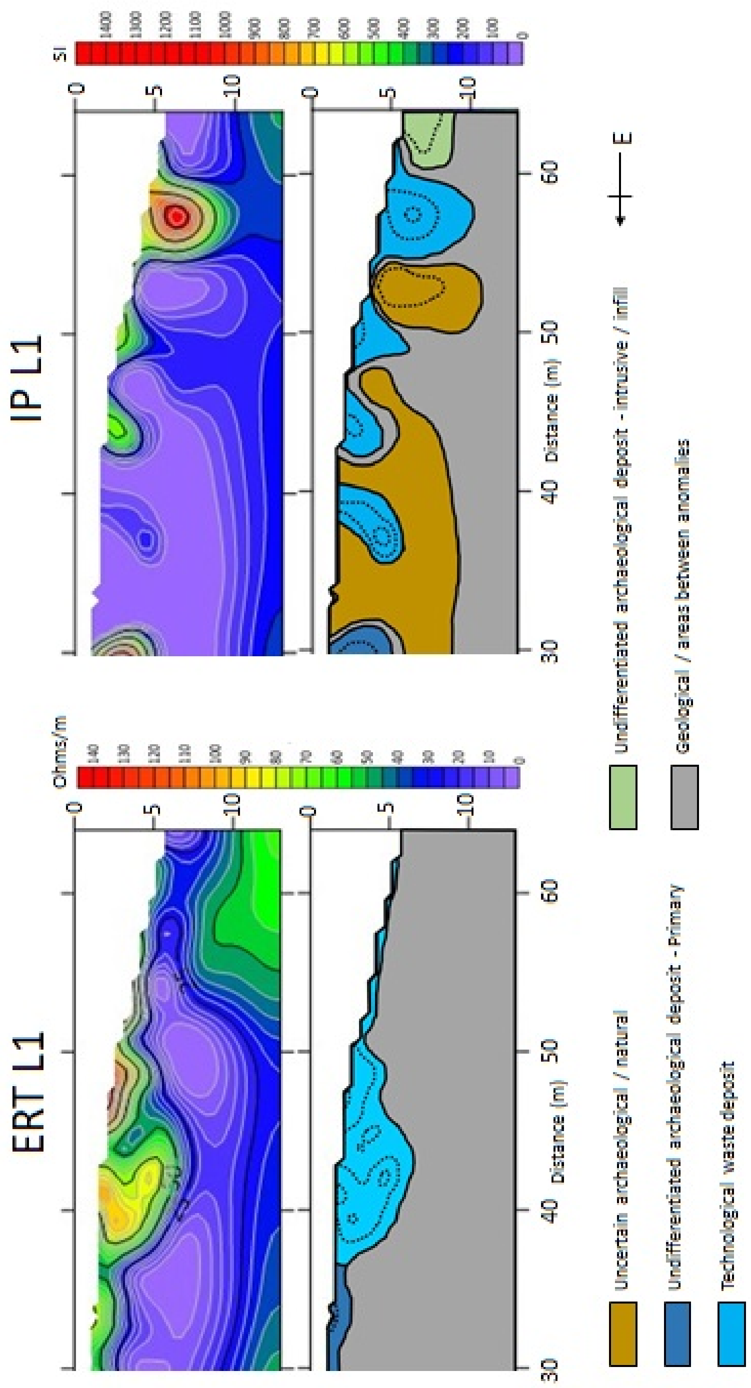


FIGURE 8.4: Composite of TWD response to ERT/IP, normalised and interpreted, Standen L1

Induced polarisation

With the IP lines at Chitcombe being in the same position as the ERT, the TWD is represented in the same lines in the same physical position (fig. 8.3) Throughout the lines the response shows large variations from a possible high of 950 units in line 12 to a low of 0 units across lines 10 to 12. The larger sections of the TWD across lines 10-12 are represented by low polarisation measuring below 100 units. At the western end of line 4 (fig A.54), the TWD shows as a strong polarising anomaly in the same position as an anomaly in the matching ERT line (fig A.42). This shows the deposits do not react in a consistent way to IP survey.

The same is the case for the position of the IP surveys at Standen and therefore the TWD (fig.8.4), which has a highest reading of 1400 units. The area of the TWD at Standen is not represented by a coherent deposit, rather a number of discrete deposits (light blue) with large areas of uncertain (gold) measuring below 50 units. However, due to such high readings in this survey some of the finer detail has been lost. With an extremely large difference in the range of readings at Standen it can be seen that the TWD does not react in a consistent way to IP surveys. At both sites the high responses are therefore interpreted as denser concentrations of specific material types, which have not been identified.

Both sites show a large range of responses to the TWD. It is known that these types of deposits are not heterogeneous so would not be expected to show a uniform response. It has been seen from the material sampled in excavation that small amounts of ore are distributed through the TWD. It was believed this technique would pick up this deposit. This is not the case on either site. With large sections of the TWD's on both sites measuring below 100 units, it could be said that it does not react to the IP survey, and with responses similar to the natural geology it could be the fine residue reacting. However, there are high readings associated with the TWD on both sites showing a material must be reacting. This could either be a specific material that was not identified in this project or a specific waste material, such as ore, this is in a more dense concentration to be detected by this survey type.

In-phase - Electromagnetic

The only in-phase survey to intersect with a TWD is at Chitcombe field 2 (fig.8.1). Within the EM surveys the TWD is positioned on the very northern edge of the survey and both the 15kHz and the 3kHz in-phase surveys is represented by very low readings, 1500ppm and -2000ppm respectively (fig. 8.5). This is a highly unexpected result as the TWD shows as a highly magnetic response in the magnetometer survey but low to negative in the in-phase. The possible reason for this response has been set out in chapter 3, with the description and operation of this survey type. However, the most logical explanation is the 'circular' scale effect which happens when the surveying equipment is in the vertical dipole position which gives a higher degree of sensitivity and can producing a 'flipping' effect where extreme readings can jump to the opposite end of the scale (pers comm Neill Wood). It is therefore suggested here that the low response, particularly when the data turns negative in the 3kHz, is actually representative of extremely high magnetism. The data changing to negative between the 15kHz and the 3kHz surveys shows a change in the TWD

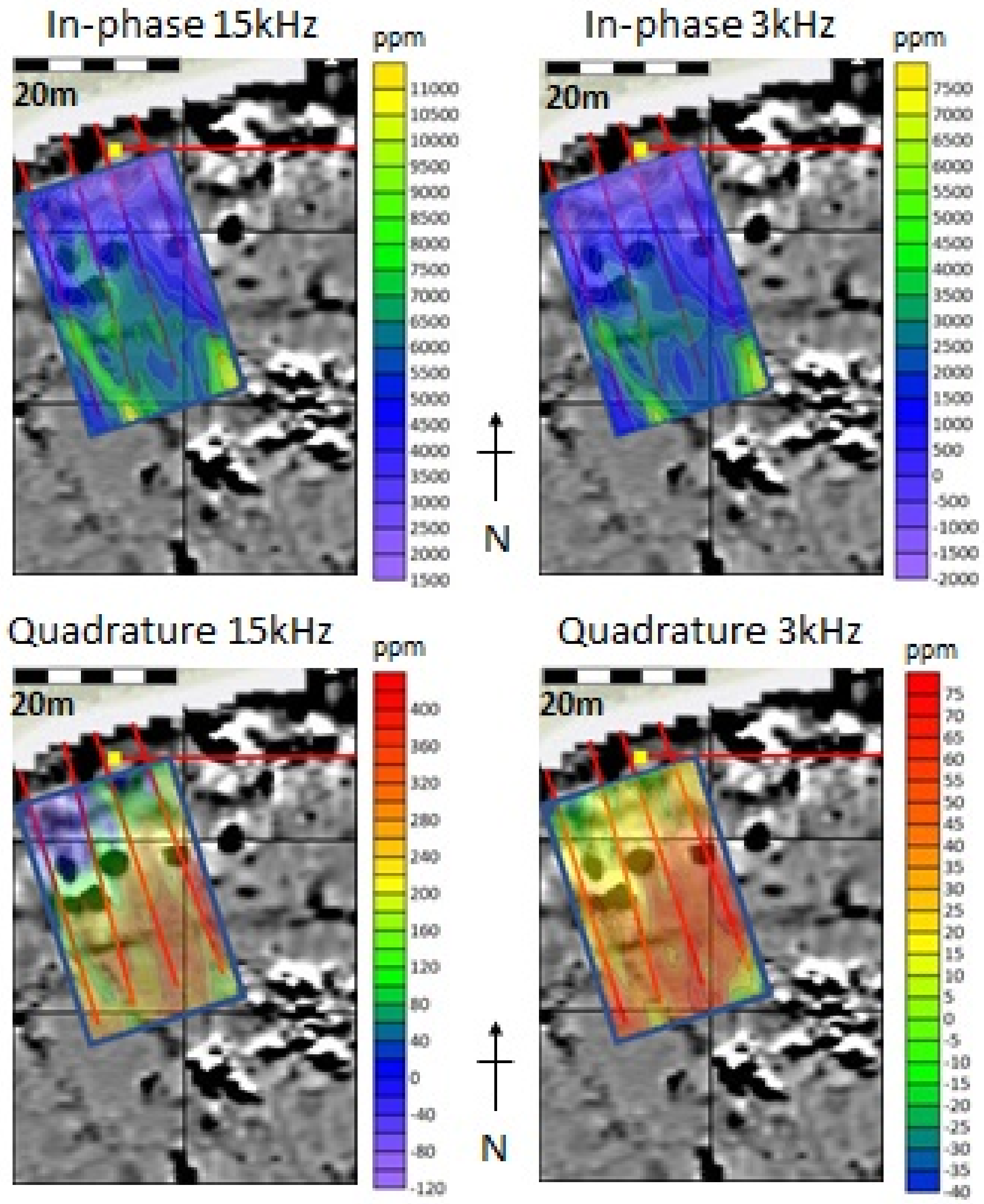


FIGURE 8.5: Chitcombe field 2, EM in-phase and quadrature over magnetometry

with depth.

The TWD gives an extreme response to in-phase EM survey. The explanation for this would come down to the material present and the formation of the TWD. The material collected through excavation shows a large amount of magnetic material in the waste deposit including slag, and roasted iron ore which would react to the in-phase survey. The TWD is also known to exist to a depth of almost 2m in this area. As the EM surveys are collected as a volume of the area of ground the electromagnetic field penetrates, the magnetic material at this point in the survey is going to constitute a large portion of that volume, therefore having a greater effect on the readings. This will also explain why these low responses are occurring in the TWD and not for the spread of technological waste in other areas. The science behind the EM techniques and the reasons for this inversion from positive to negative and vice versa is beyond the scope of this project.

Quadrature - EM

The quadrature survey are in the same position as the in-phase, therefore so is its relative position to the TWD (fig.8.5). In both the 15kHz and 3kHz the TWD is represented by low readings on the northern edge of the survey, including negative readings in both. The 15kHz survey has lowest discrete readings of -120 ppm and the 3kHz -40 ppm. The overall TWD has a lower response in the 3kHz survey measuring from 15-0 ppm whereas in the 15kHz survey the response is 100-0 ppm. However, in the 15kHz survey the west of the survey area has a reading of -120 ppm whereas in the 3kHz it measures -40 ppm. The TWD is present in both frequencies, but the material that is causing the strong negative response is nearer the ground surface as it is more prominent in the 15kHz survey. The two surveys show the response from the TWD is not consistent and shows the potential for this survey type to identify concentrations of specific materials.

Discussion

When looking at the information presented, all survey techniques have added their own information to the analysis and interpretation of the TWD. The magnetometer survey can be used to locate the position and extent of the TWD laterally. However, great care must be taken as a general spread of technological waste can give the same response as a more concentrated TWD and therefore can be misleading. The ERT demonstrates well its ability to give an estimation of the depth a vertical form of the TWD along with possible differences in the deposit. However, its ability to identify the TWD is questionable. IP has the ability to identify specific materials giving an indication as to what is potentially in the TWD and areas to target. However, it does not give an indication as to the shape/configuration of the TWD. The in-phase EM survey shows the potential for this technique in identifying the main body of the TWD, its depth, and concentrations of magnetically susceptible material. However, due to the way this technique works it returns some obscure results which need further investigations beyond this project. The same can be said for the quadrature EM survey, showing potential for identifying the core, depth and changes in conductive deposits, but also returning occasionally obscure results.

8.2.2 Furnace

The furnace is an important feature on an iron production site for answering the aims of this project. It helps to identify where the smelting was occurring on the site, giving information on organisation and function. This type of feature will be analysed in more detail here with reference to the different geo-prospection surveys used in both case studies.

Magnetometry

At Chitcombe eight potential furnaces have been identified, four each in fields 1 and 2 (fig 8.1), and in the field survey at Standen, potentially 3 (fig 8.2).

At Chitcombe the furnaces are contained within the smelting workshops. The smelting workshops have similar forms in field 1 and 2 as can be seen in figure 8.1. The furnaces are positioned together in an east/west orientated line, roughly evenly spaced. This orientation matches that of the ghyll and stream that form the northern boundary of the site. The furnaces are positioned along the top of the ghyll adjacent to the TWD.

The magnetic responses from the individual furnaces in field 2 (fig.8.1) show them a thick dots, which have been coloured red as part of the interpretation categories, and measure between 293-1000nT. The furnaces in field 1 have the same form and measure up to 1000nT. All of these furnaces have halos of negative magnetism around them which is expected of such high magnetism and is an effect of the surveying equipment. An interesting difference between the two sets of furnaces is in field 1 there is an associated deposit directly to the north of the furnaces, that has been marked as a primary deposit, with readings up to 150nT. This could represent an extension of the furnace setting where material would be dropped after being pulled out the furnace or the floor heat-affected due to slag tapping, both creating increased magnetism. The fact that this associated magnetism is not present near the furnaces in field 2 could show a difference in working practices between the two workshops.

The three furnaces identified at Standen, coloured red in figure 8.2 have magnetism measuring between 453-1000nT. Two of these furnaces are positioned on the northern and eastern edge of the working area. This shows a possible organisation on the site. It is unclear if these furnaces would be contemporaneous or representing different phases of smelting on the site. The third furnace is positioned away from the working area to the north. A number of small magnetic anomalies are positioned to the south of this furnace heading towards the working area. This could indicate this furnace is also associated with the smelting area despite its differing position compared to the other two furnaces.

All three individual furnaces have a similar form of shape being a thick elliptical dots. Due to this similarity in shape, a standardised construction and use of the furnace could be inferred. The similar shape could also indicate that the furnaces are contemporaneous, or there is a standardised practice over time. The orientation of these furnaces is associated with the working area as can be seen in figure 8.2 rather than the ghyll. However, the TWD runs along the ghyll-side to the west of the working area and furnace.

When looking at the response of the furnaces to the magnetometer survey across both sites it can be seen that there is a large range in the magnetic responses. However, even the lowest magnetism is higher than would be expected of an archaeological feature which helps with the interpretation of the smelting furnace. The positioning of these anomalies on or near the ghyll-side edge seems to be a standard practice. This shows an organisational practice that transcends the scale of the site and will be further discussed in chapter 10. There is also a standard response of the furnaces being circular to slightly elliptical across both sites.

Earth Resistivity Tomography

The only confirmed example of a furnace in the ERT surveys is at Chitcombe in field 2, line 10 (fig.8.6) and is defined in the interpretation as red and pink anomalies. ERT line 10 crosses the magnetic response in the magnetometer survey at 15m (fig 8.1). There are two sets of anomalies at this point, the first descends roughly 2m from the ground surface, with its highest resistivity of 210 Ωm at its base. The second, which is deeper measures up to 150 Ωm. These are believed to represent the back and the base of the furnace, being open to the north, the direction of the TWD, and containing a lower resistivity anomaly at its centre, pink, that measures down to 0 Ωm which is believed to represent a form of fill. The set of anomalies to the north centred on 10m takes a very similar form, comprising features consists of two increased resistivity anomalies, one descending from the ground surface and the other forming its base with a low resistivity centre, and although not in the magnetic anomaly that represents the furnace, it is believed to show the possible wider construction of the furnace with a possible area at the front for working and tapping the slag.

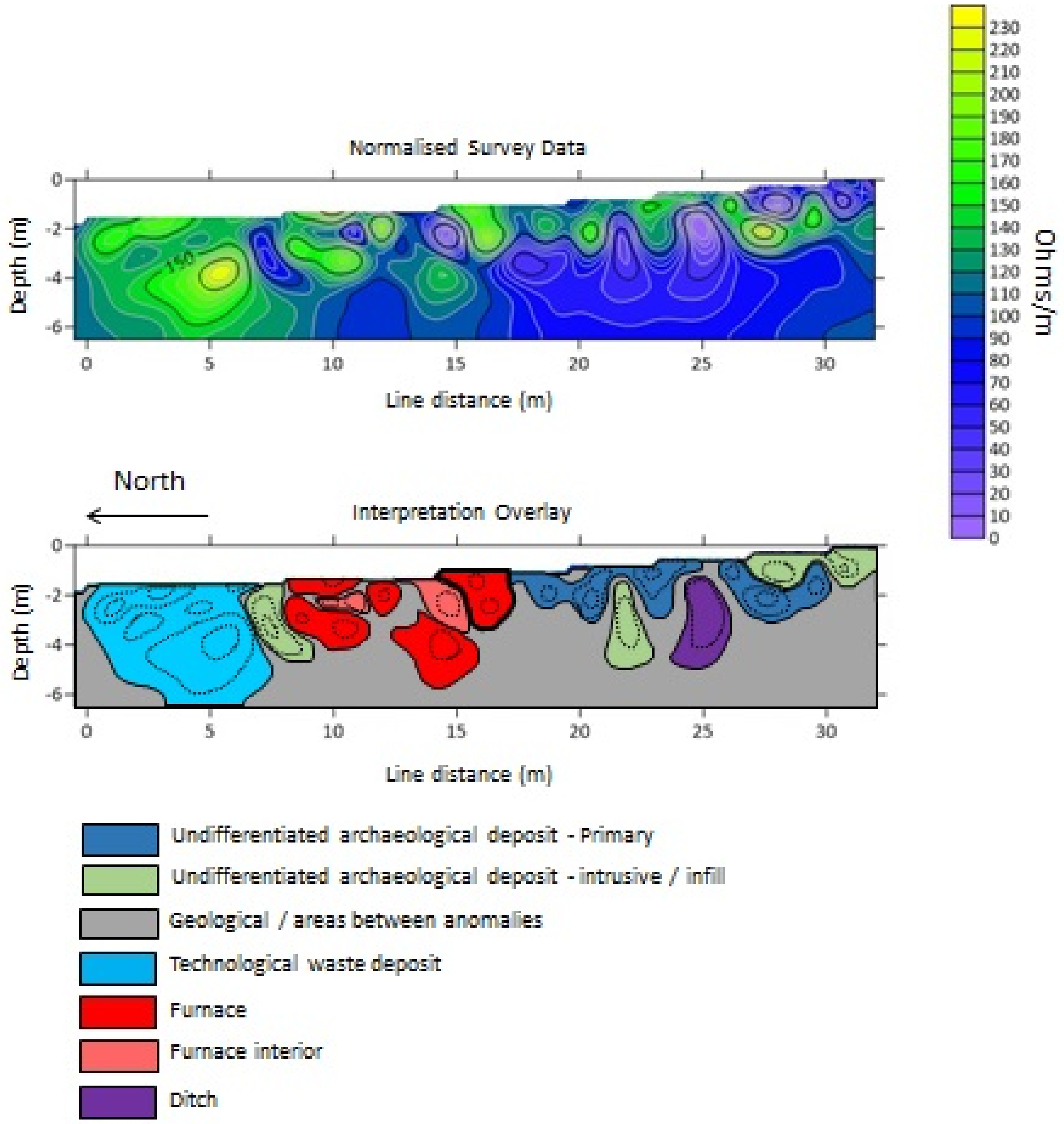


FIGURE 8.6: Chitcombe ERT line 10, normalised and interpretation overlay

Although this is the only ERT line that crosses a furnace according to the magnetometer survey, there are a number of other features throughout the ERT surveys that take a similar form. This configuration is repeated a number of other times across both sites. At Chitcombe it is present in Line 6 (fig.A.44).

In this instance the anomaly is positioned within the area that might represent a building or structure. This is of interest as it potentially shows the use of this area in the smelting process. However, this is not confirmed in the magnetometer survey so is unlikely to be a furnace.

At Standen a similar structure can be seen twice in Line 3 (fig.8.7), at 21m and 32m represented int he interpretation image by dark blue primary deposits around light green intrusive/fill deposits. These are both positioned within the working area on the site and could represent older furnaces that were dismantled or a different structure with unknown use.

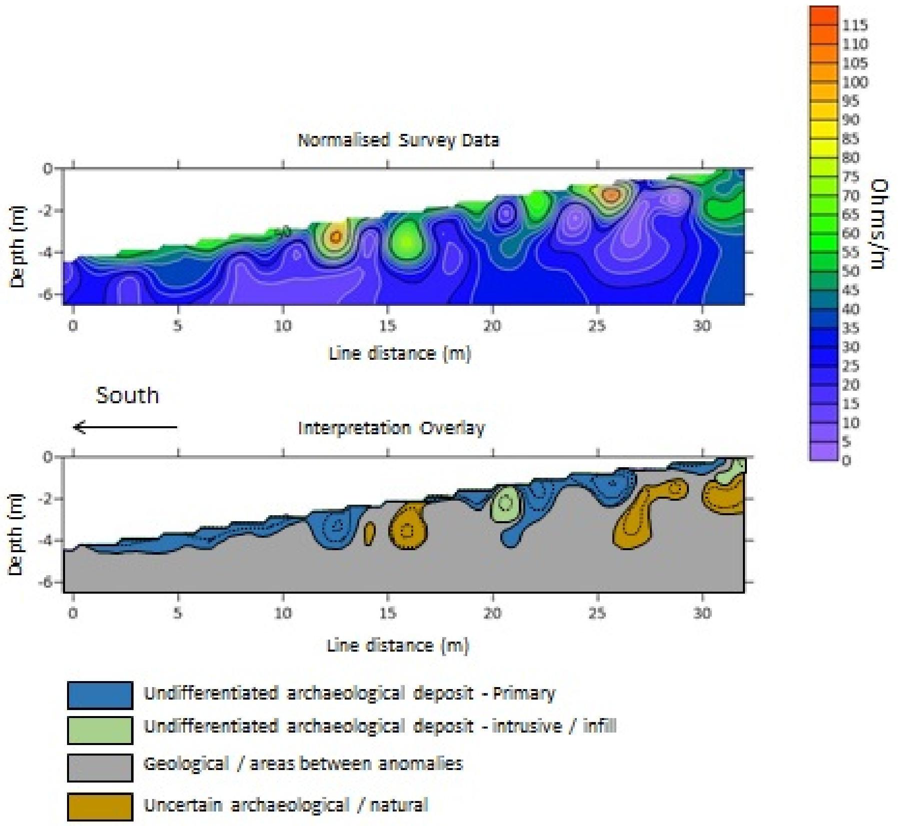


FIGURE 8.7: Standen ERT line 3, normalised and interpretation overlay

Induced Polarisation

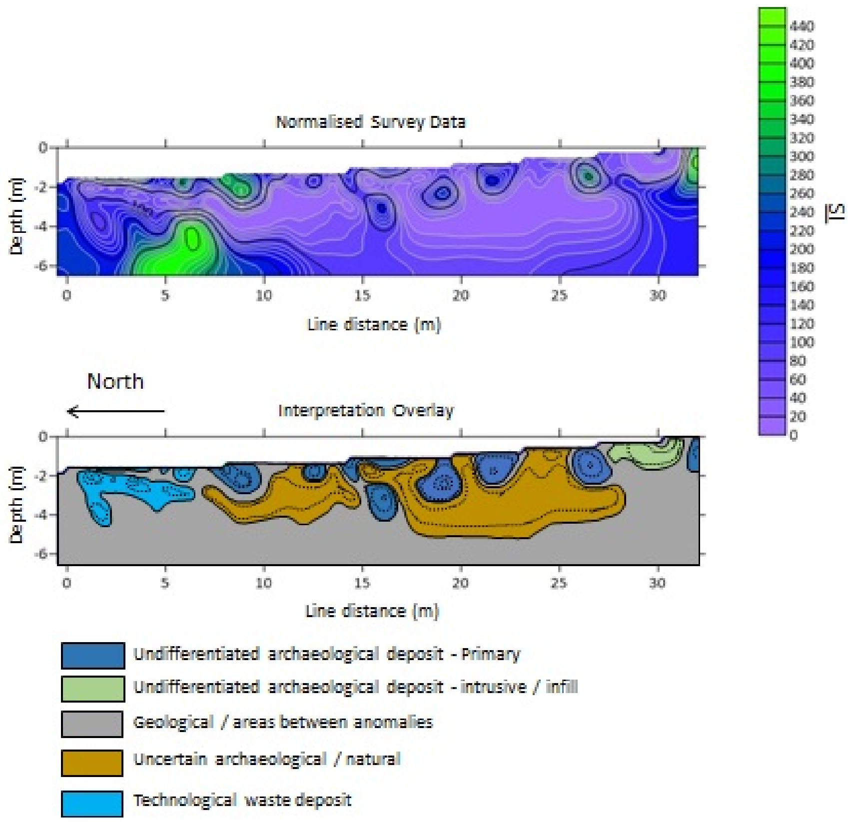


FIGURE 8.8: Chitcombe IP line 10, normalised and interpretation overlay

Looking at the area between 8-16m on Chitcombe IP line 10 (fig 8.8) where a furnace has been identified in the ERT survey (fig 8.6), it can be seen that there is no clear response. This shows the possibility that a furnace structure, consisting of baked clay and possible geological material, does not react to the IP survey.

At Standen, it can be seen in IP line 3 (fig. 8.9) that anomalies near the ground surface at 20m and 30m are in the same position at those in the ERT survey (fig. 8.7) that were interpreted as a similar form to the furnace seen at Chitcombe (fig. 8.6). The anomaly at 20m is been categorised as a primary deposit (dark blue) measuring 400 and the anomaly at 30m has been categorised as uncertain (gold) with a reading of 1400. This shows that the material present in these positions are creating responses in both the ERT and IP. With no clear magnetic response over these anomalies and the response from the IP, where there was none at Chitcombe, it can be said these are not furnaces but another type of feature. However, this cannot be said for certain and would need to be confirmed with further research.

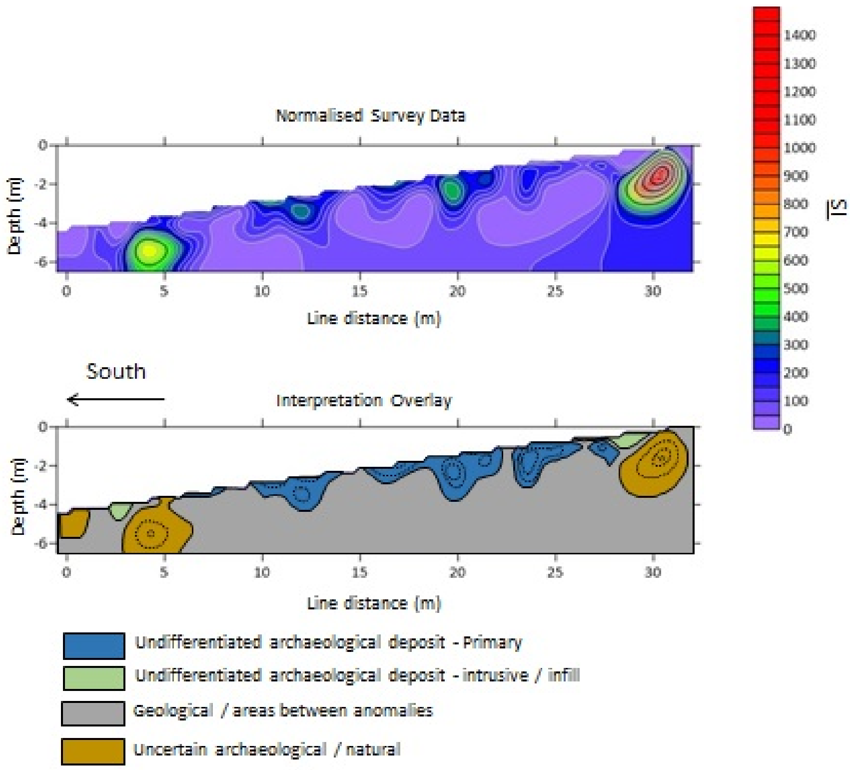


FIGURE 8.9: Standen IP line 3, normalised and interpretation overlay

In-phase - Electromagnetic

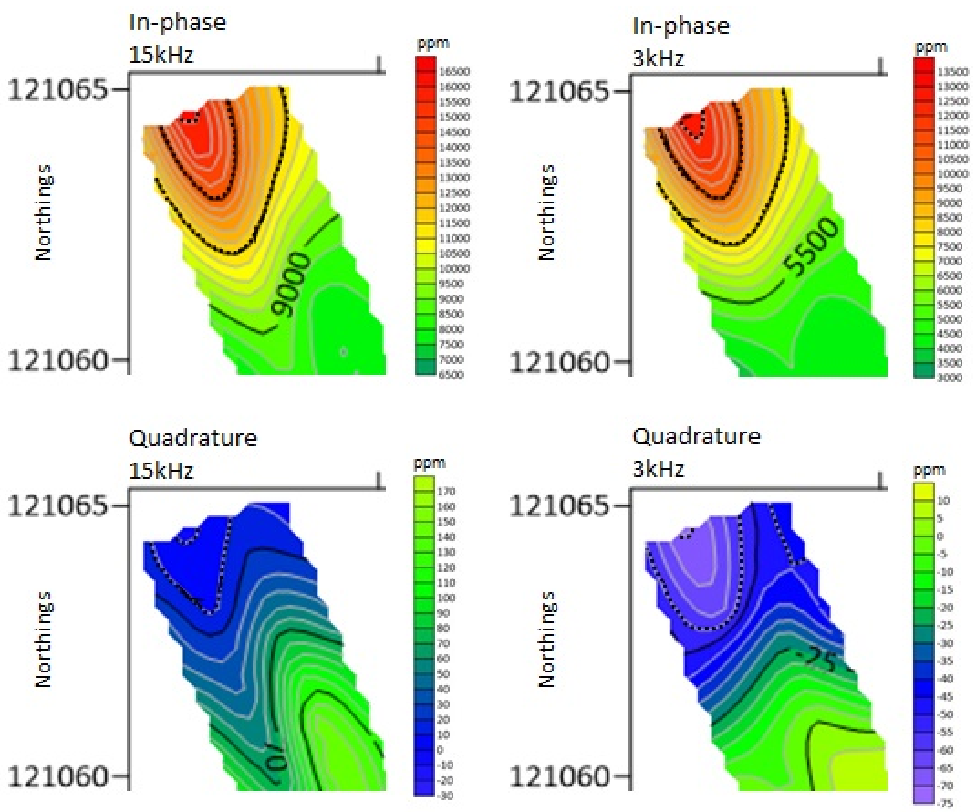


FIGURE 8.10: Composite of EM in-phase and quadrature response to furnace, Chitcombe field 1

A furnace was partially surveyed at the north end of the in-phase survey at Chitcombe, in field 1 (fig.8.11). The furnace reacts the same way at both 15kHz and 3kHz with near identical anomalies in form, including the core of the anomaly on the very northern edge of the survey being in the same position (fig. 8.10). The only difference is that the 15kHz survey has slightly higher readings implying the deposits are nearer to the ground surface. Although only the back half of the furnace has been surveyed, a clear structure can be seen of a highly magnetically susceptible core decreasing in all directions, forming a semi-circle against the northern edge of the survey, presumably then forming a full circular structure to the furnace. It is known from excavations that furnaces in this area contain a large amount of iron ore fines (ap B.2). It is unclear as to whether the response is from the furnace or the iron ore content.

Quadrature - Electromagnetic

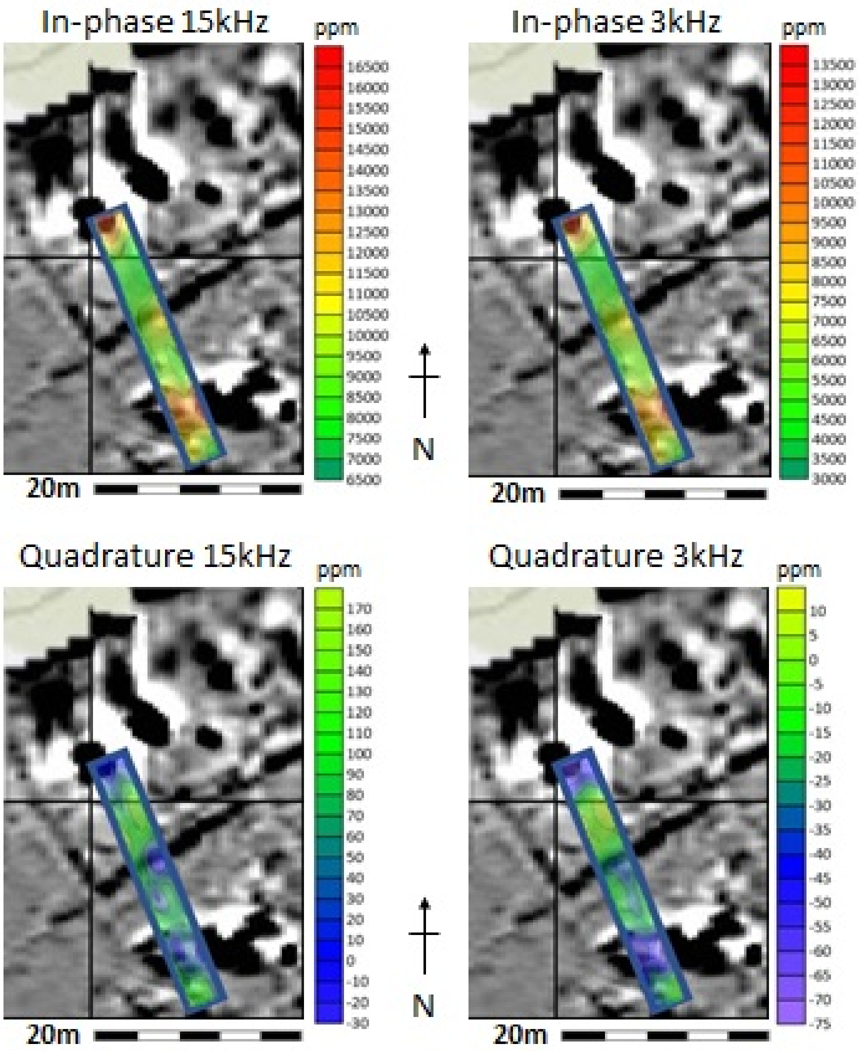


FIGURE 8.11: Composite of EM in-phase and quadrature surveys over magnetometry survey, Chitcombe field 1

Figure 8.11 shows the position of the quadrature survey is the same as the in-phase with the furnace being covered in the same position. The furnace reacts in the same way in both the 15kHz and 3kHz as a lower quadrature anomaly (fig. 8.10). It shows a response of low conductivity down to 0 ppm in the 15kHz survey and -70 ppm in the 3kHz survey. In both these surveys the core of the anomaly is in the same position on the northern edge of the survey. The change in readings show that the material causing the anomaly is slightly deeper as it is more prevalent in the 3kHz survey.

Discussion

It has been seen that in the EM surveys at Chitcombe field 1 the furnace is present. However, using EM in field 2 no furnaces are present in either the in-phase or quadrature surveys, when according to interpretations from the magnetometer survey, and supported by data from the ERT and excavations there should be four furnaces (fig8.5). This then raises questions as to the representation of the furnace in in-phase and quadrature or whether it is another material causing the response. During excavations in field 1, it was discovered that a furnace in this area contained a large amount of roasted ore in the internal cavity as well a large stones in the furnace wall. This could show that the burnt clay that forms the furnace is easily masked but background magnetism and quadrature from spread technological waste.

It could therefore be argued that the in-phase and quadrature EM surveys in field 1 are not detecting the furnace but rather the large volume of geological material contained within it. This same response happens at the southern end of both EM surveys in field 1 in the working area that also contained a large amount of iron ore, as identified in trenches 20 and 21 (ap B.2), which reinforces the interpretation that the response is due to the geological material rather than the furnace. The lack of response from the furnaces in field 2 shows the ability for features within a site to be masked by other material or background readings. The use of this survey type for the identification of a furnace is therefore unclear, however, it could give an indication as to the material that may be present, for example large amounts of roasted ore, leading to a better understanding of the deposits present or smelting processes that might be occurring.

The anomaly present at 20m on Standen line 3 (fig. 8.7), has been seen to be similar to the response from the furnace on Chitcombe line 10 (fig. 8.6). The anomaly coincides with a small increased magnetic anomaly in the magnetometer survey. This anomaly had not been identified as a possible furnace as it does not match the size or shape of the others identified across the two sites. This could raise the issue of possible confirmation bias when interpreting iron production sites, looking for large strong magnetic features to interpret as the furnaces.

Each survey type has been seen to add its own unique data for the analysis and interpretation of a furnace, however there does not look to be a standard set of responses that can be said to positively identify a furnace across all techniques. The magnetometry survey allows for a rapid assessment of the positioning of the furnace within the site and its initial interpretation. The ERT survey gives an understanding of the possible structure of the furnace. The IP, in-phase and quadrature EM surveys then give information on the material present in the furnace to give an understanding of the processes occurring.

8.2.3 Working areas

The working areas are being defined as areas which are associated with smelting, either directly or indirectly through material processing. These are seen as an important feature as they help in understanding the organisation of the site. There are a number of working areas to be discussed across both sites. At Chitcombe this includes the area in field 1 which combines the smelting workshop with an area just to the south which is marked by a dotted white line on the magnetometer survey in figure 8.1, as well as the smelting workshop in field 2. A discussion will also be had on the area across the track in field 2 that has been categorised as primary deposition as well as the area of secondary deposition that covers the north-east of field 2 where much of the fieldwork for this project took place. At Standen this includes the area between the furnaces categorised as secondary deposition in the field in figure 8.2.

Magnetometry

The working area in Chitcombe field 1 consists of a number of features. Most notable are the two irregularly-shaped magnetic anomalies with readings up to 412nT, the largest of which has been categorised as primary deposition (fig. 8.1). The high magnetism here represents a concentration of roasted iron ore as seen through excavations in trenches 20 and 21 (ap B.2). Within this wider area is a number of linear and right-angle features, coloured green in the magnetometry interpretation. These could be interpreted as foundations or demarcations of structures or sub-areas, which along with the deposit of roasted ore fines show working or storage areas associated with material preparation for smelting which would occur in the smelting workshop itself. The width of all these features matches that of the smelting workshop which would add to the interpretation that all these features are linked.

When looking at both smelting workshops it can be seen that the areas around the furnaces are not formed of mixed magnetism. During excavation it was noted that the smelting workshop in field 1 (trench 18) was devoid of technological waste on the floor around the furnace, indicating a practice of cleaning of material. This was also the case in trenches 10 and 12 in the field 2 smelting workshop (ap B.2). A notable feature within the field 1 smelting workshop is a magnetic anomaly with magnetism up to 427nT, coloured orange in figure 8.1. This feature has been identified as a post-hole in trench 23 (ap B.2). This could show a large structure within the smelting workshop. In the smelting workshop in field 2 there is a large magnetic anomaly to the south of the western-most furnace. This anomaly has magnetism of at least 1000nT. This could be compared to the working area in field 1 which would imply this feature is caused by a deposit of roasted iron ore.

The possible working area in the centre of field 2, on and to the north of the trackway and interpreted as a primary deposit (light blue), is represented by mixed increased magnetism with readings up to 600nT. Magnetism of this magnitude has been associated with extreme burning or concentrations of iron ore. Another possibility for high magnetism on an iron production site is smithing debris. This area has no apparent structures. However, it is positioned across the trackway near the possible habitation area so could possibly be a bloom smithing area.

At Standen the working area is represented by an area of mixed magnetism up to 300nT. This area has no formal structure, but seems to be forming a semi-circle truncated by the edge of the survey and curving towards the two nearest furnaces. There is increased magnetism to the northern end of this area in front of a furnace. This area can be interpreted as a hard standing, due to a spread of technological debris, which is more concentrated in front of a furnace. The response of this area is more similar to that of the north-eastern corner of field 2 at Chitcombe (8.1) which as been shown in excavation to be a generalised spread of technological waste interpreted as a made floor surface. This could be seen to show that material is utilised or builds up in areas that are frequently used.

Earth Resistivity Tomography

At Chitcombe the working area around the furnaces has been covered in ERT lines 10-13 (fig A.47, A.48, A.49 and A.50). In all these survey lines there is coherent increased resistivity along the ground surface within the smelting workshop, between the TWD (light blue) and the ditch (purple) with discreet higher resistivity anomalies within. The general area across these survey lines has a resistivity between 130-200 Ωm. The discreet increased anomalies then have resistivity up to 300 Ωm. All these anomalies have been categories as primary undifferentiated archaeological deposits with no clear interpretation apart from a made-up ground surface consisting of spread of technological waste with potential other features. This same pattern of undifferentiated archaeological deposits forming the anomalies along the ground surface can also be seen in lines 1-8 (ap A.2.2) which are not in an interpreted working area but has been identified as containing a spread of technological debris through excavation (ap B.2). This shows possible issues with the use of this technique in identifying working area.

At Standen the working area is covered in part by all three ERT lines. In line 1 a small portion of the working area is covered in the eastern end of the survey. This presents as increased resistivity measuring 100 Ωm on the ground surface. Throughout lines 2 and 3 this area is represented by a number of anomalies that vary in their resistivity. In line 2 these range from 30-80 Ωm, and in line 3, from 10-115 Ωm. All the anomalies form a variety of shapes rather than a continuous deposit. There are two possible interpretation for these responses. One is that at the lower levels of the working area at Standen the deposits are non-continuous and represent a number of discrete deposits, or that the spread of material is as a thin lens and not detected by ERT. The same as Chitcombe all these anomalies have been classed as undifferentiated archaeological deposits with no clear interpretation.

Induced Polarisation

At Chitcombe there is no coherent response from the IP survey lines 10-13 (fig. 8.12 and 8.13), across the working area in the smelting workshop. There are however a number of increased polarisation anomalies, up to 950 units. These anomalies are seen as random deposits of polarising material within the working area with no interpretative structure or coherency and all being categorised as undifferentiated archaeological deposits. The same issue exists with this technique, as with ERT, in its ability to identify working areas.

At Standen the working area in survey lines 2 and 3 is represented by a number of anomalies. These do not form a coherent working surface but rather are randomly distributed. As discussed, two of the increased polarisation anomalies in line 3 (fig. 8.15) are in the same position as features identified in the ERT survey that look like furnace structures. The other anomalies in line 3 have readings between 200-600 units. In line 2 (fig. 8.14) all anomalies are between 100-260 units. These seem randomly distributed throughout the survey with no interpretation as to the structure of their deposition.

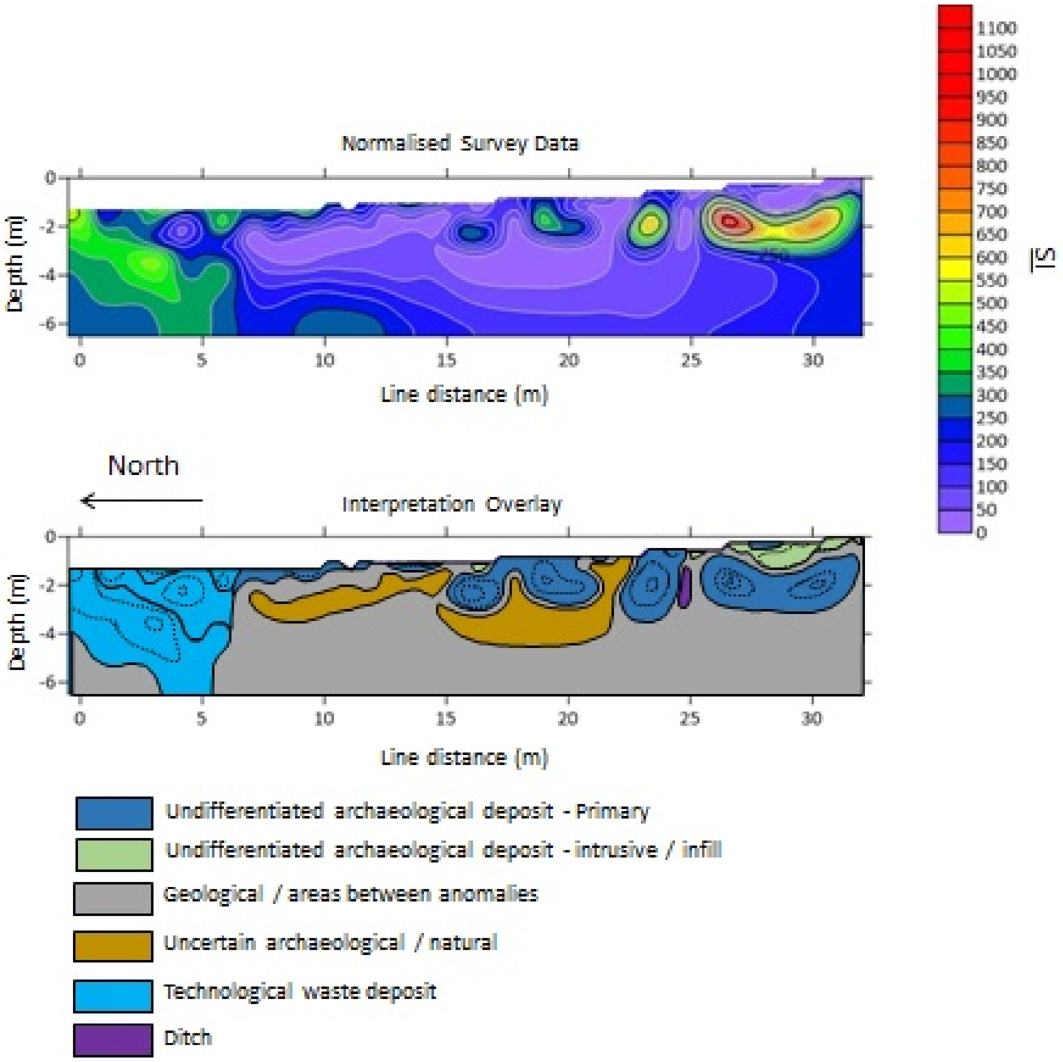


FIGURE 8.12: Chitcombe line 11 IP interpretation

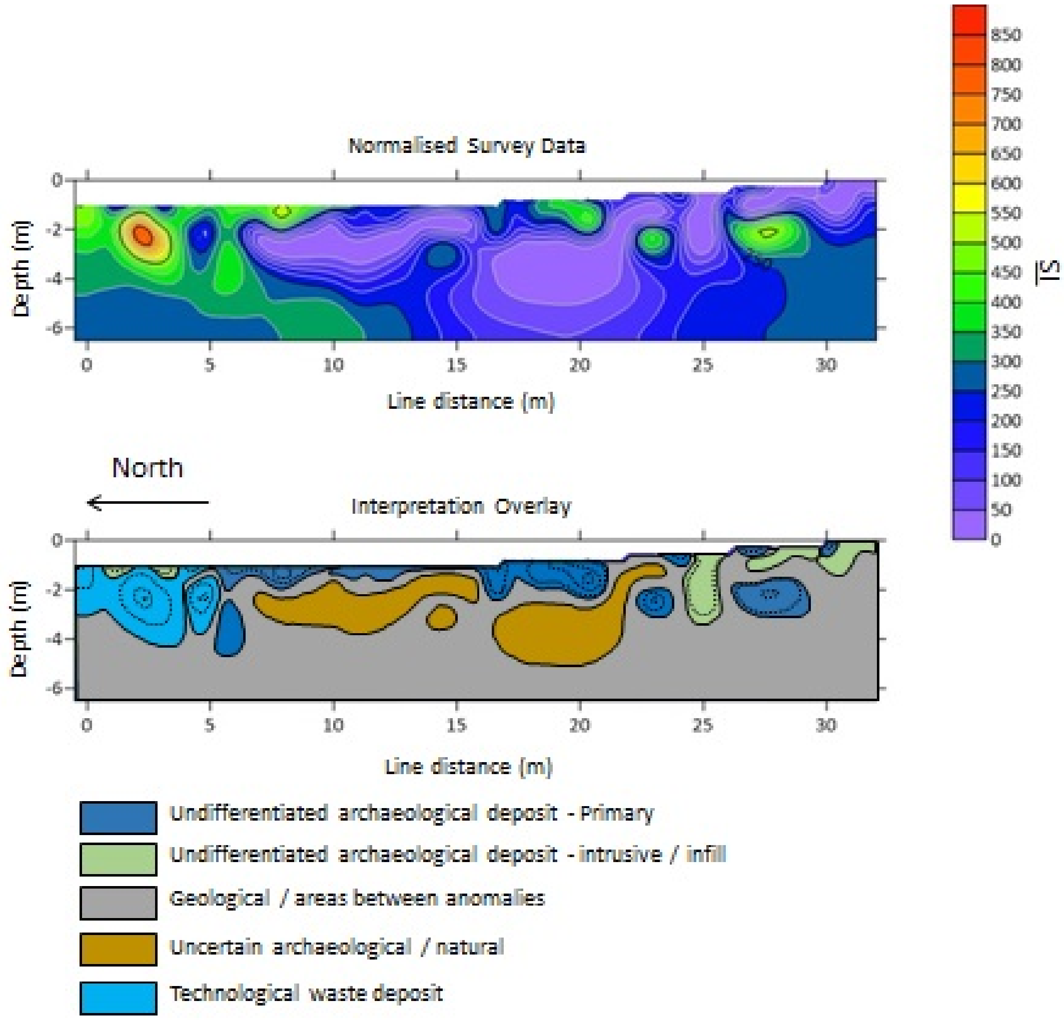


FIGURE 8.13: Chitcombe line 13 IP interpretation

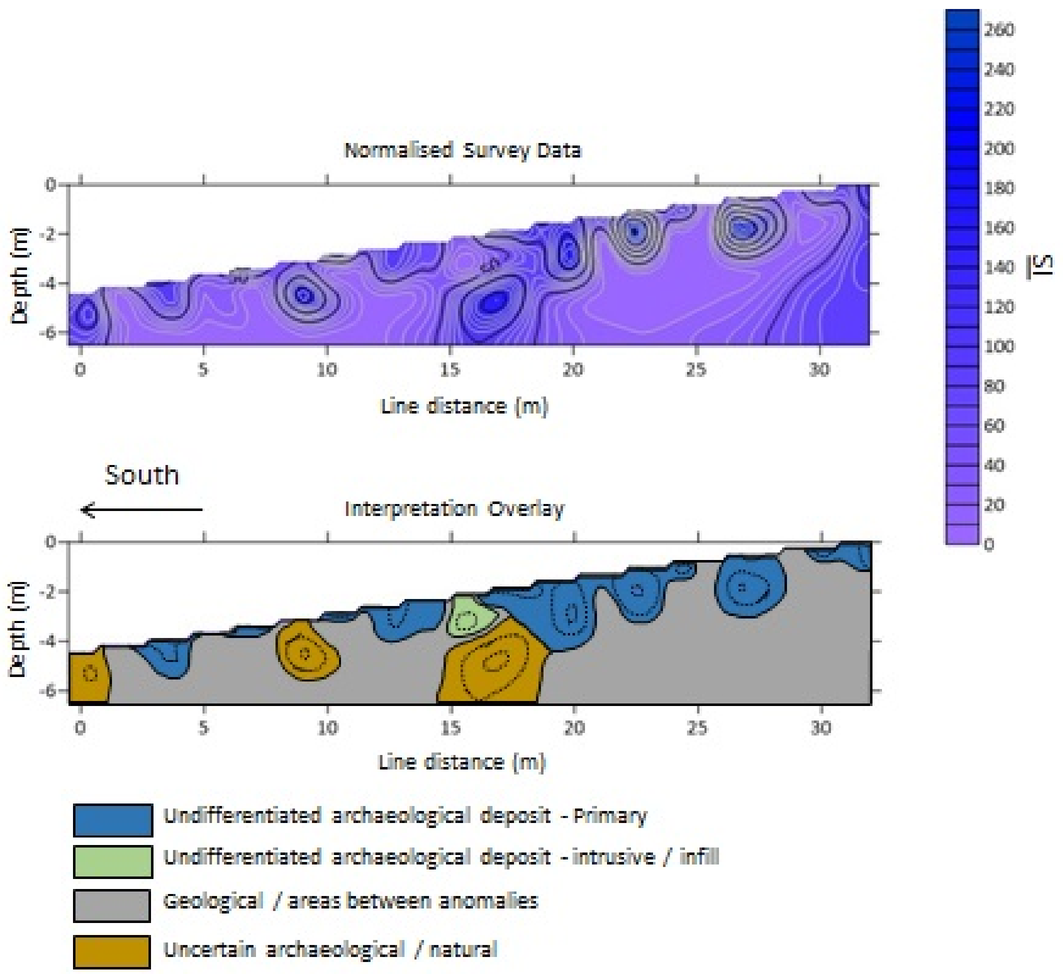


FIGURE 8.14: Standen line 2 IP interpretation

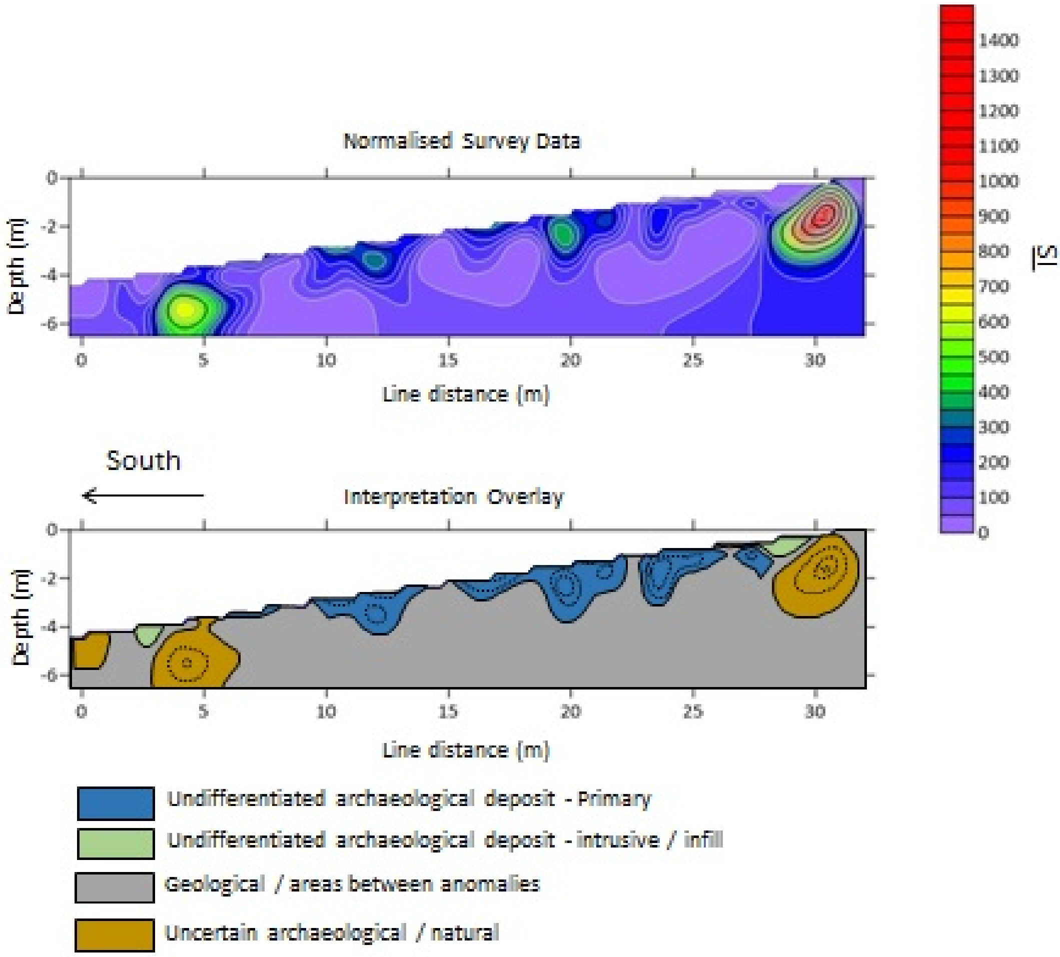


FIGURE 8.15: Standen line 3 IP interpretation

In-phase - Electromagnetic

At Chitcombe the working area within the smelting workshop has been covered in both field 1 and 2 (fig 8.11 and 8.5). The area in field 1 shows a similar response in both the 15kHz and 3kHz surveys. This presents as a magnetic susceptibility of around 8000ppm in the 15kHz and 5000ppm in the 3kHz. There are no notable anomalies within this area. It can therefore be interpreted that this area is formed of a homogeneous spread of a similar material. However, it is unclear if this represents a spread of material or the response to the natural geology.

The area in field 2 has an unclear response across both frequencies. In the 15kHz the area contains readings of around 4000ppm to the east and the west. In the centre of the area is an expanse with readings of around 6000ppm, which extends south over the smelting workshop ditch beyond the working area. This is the same case in the 3kHz survey with the areas to the east and west measuring around 500ppm and the central area extending south across the ditch measuring around 3000ppm. The area of increased magnetic susceptibility that extends over the smelting workshop ditch represents, with a fair level of confidence, a later spread of material as it does not match the known features and is masking their responses. Moreover, with a higher response in the 15kHz surveys it can be said it is nearer the ground surface.

At Standen the in-phase surveys, both in the 15kHz and 3kHz, are in the position of the lower portion of the working area (fig 8.16). The results from both the 15kHz and 3kHz surveys are very similar in form with the 15kHz survey being almost uniformly 3000ppm higher than the 3kHz. The fact that the shape

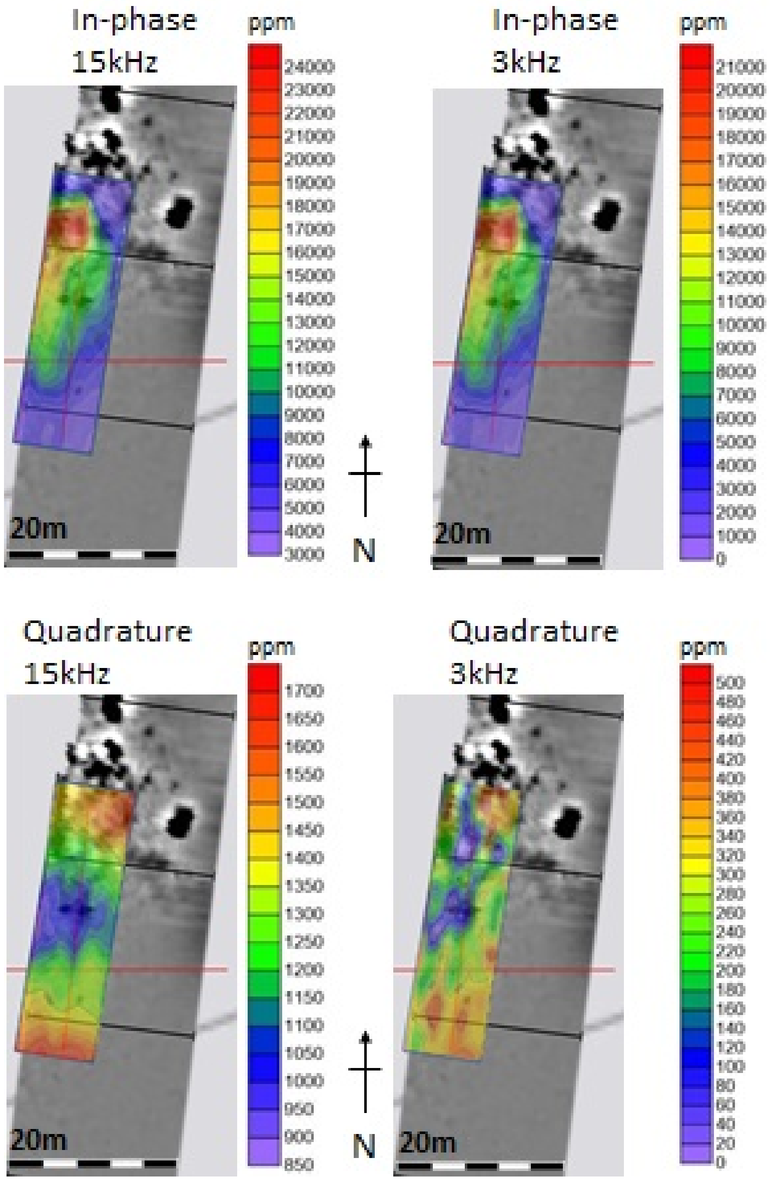


FIGURE 8.16: Composite of EM in-phase and quadrature surveys over magnetometry survey, Standen field

of the anomalies is similar between the two surveys shows that the deposit is positioned across both depths with little change, with the decrease between 15kHz and 3kHz showing the main body of the deposit is nearer the ground surface. These surveys show the main body of magnetism is in an area towards the northern end of the survey. The area of magnetism spreading south from this possibly represents material being spread over time.

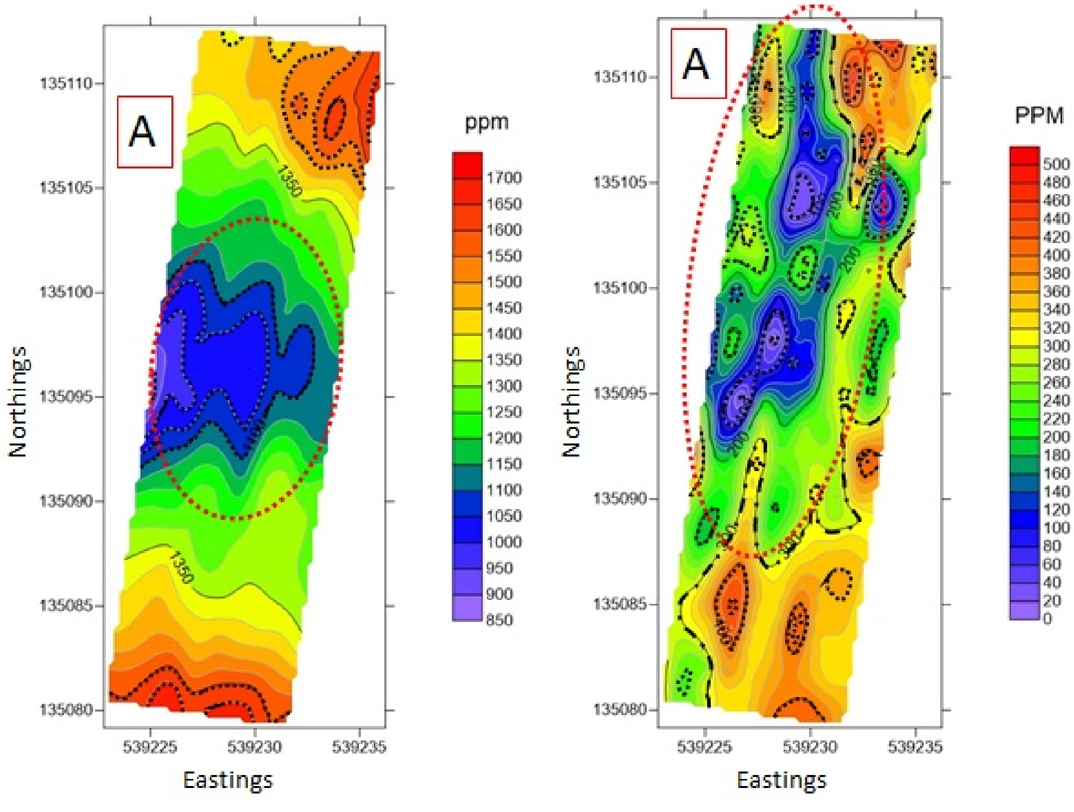
Quadrature - Electromagnetic

Field 1 (fig. 8.11) shows a similar response between the 15kHz and 3kHz surveys. This presents as an area of between 110-140 ppm in the 15kHz and 0-10 in the 3kHz, with the highest readings biased towards the east of the area. It is unclear if this slight increase in both surveys defines a discreet anomaly or just fluctuations within the deposit.

In field 2 (fig. 8.5) the area that is identified as the working area within the smelting workshop is indistinguishable in the survey due to the large area of increased conductivity that dominates the southern half of both surveys obscuring not only the working area but also the smelting workshop ditch and possibly the furnaces.

At Standen the quadrature surveys, both at 15kHz and 3kHz, are in the position of the lower portion of the working area. Looking at the 15kHz survey it can be seen that there is a single area of low conductivity (fig8.17a), measuring down to 850 ppm, biased to the west of the survey and increasing in all directions. The southern edge of the survey and the north-east corner have the highest conductivity measuring 1700 ppm. The interpretation of this deposit and its form is unclear. However, there is a magnetic anomaly at this position.

In the 3kHz survey there is an area of reduced conductivity, with readings between 0-240 ppm, in the centre and northwest (fig.8.17b). To the northeast and south there are anomalies of increased conductivity, measuring from 260-500



(A) Standen quadrature 15kHz

(B) Standen quadrature 3kHz

FIGURE 8.17: Response of the working area to quadrature 15 kHz and 3 kHz, Standen

ppm. The area of decreased conductivity is in the position of the expected working area. It can therefore be said that this low conductivity deposit represents a spread of material associated with the smelting process. This response is not homogeneous across the area showing a disparity in the amount of material deposited. The area of increased conductivity could also represent a spread of material, but it is believed that it more likely represents the response from the natural geology.

The deposits at Standen show a great difference in form and readings between the 15kHz and the 3kHz quadrature survey, indicating a substantial change in the deposit. There are two possible explanations for this change. The first is that there are two different phases in the area, representing two different periods in time or activity which have changed the deposit. The other is that more modern ploughing of the field has disturbed the material in the 15kHz survey, changing the form of the deposit. It is unclear which of these is the more accurate interpretation.

Discussion

The term 'working area' is very broad and has been shown to be such through the two case studies and various geo-prospection surveys used.

When comparing the ERT and IP at Chitcombe in the working area there is no repeated correlation between the survey types. However, at Standen in lines 2 and 3, it can be seen that there is a high correlation between the increased resistivity anomalies and the increased polarisation anomalies. It cannot be said for certain at Standen that the same material is causing an increase in both. However, it can be said that the same action of deposition is causing the increase in both and therefore the materials are either the same or associated. All the anomalies within these area have been classified as undifferentiated archaeological deposits. What each of these anomalies represent is beyond the scope of this project.

It can be seen that a working area cannot be identified through ERT or IP surveys as they in themselves do not show any clear and repeating features that identify them. Example of this can be seen across the ERT and IP survey lines

1 to 8 (ap. A.2) at Chitcombe which in many cases present deposits of undifferentiated archaeological deposits in the near ground surface just like in the smelting workshops. This area has not been interpreted as a 'working area', but has been shown to contain a spread of technological waste creating an interpreted gravelled floor surface. This could then inform that an artificial ground surface is also being created in the working area. This does however show the difficulties in interpretation of a feature defined by its function more that its form.

When looking at the in-phase and quadrature EM surveys, it can be seen at Standen and Chitcombe field 2, that these two survey types can show a vast difference between the features and anomalies indicating it is not the same material causing the responses in both. As seen in the quadrature surveys at Standen there can also be a vast difference between the different frequencies. This does show that an understanding gained of the possible change in deposition with depth, and therefore time.

When looking at all the information presented, the different survey types added their own information to the assessment of working areas but it cannot be said that a standard response has been recognised. The magnetometer survey allows for rapid assessment of the working areas and their interpretation due to their proximity to other features such as furnaces. The ERT shows whether there is a hard-standing surface or deposit forming a working surface. The IP surveys can be applicable but only if reactive material is present in the deposits of the working areas. The in-phase and quadrature EM surveys can show whether a deposit has changed form over time. However, from the results from Chitcombe field 2 it can be seen that the anomalies can become masked by other deposits.

8.2.4 Ditch

The ditch is an important feature at Chitcombe as it defines the smelting workshop area and is therefore useful in understanding the organisation of the site. Ditches from both smelting workshops at Chitcombe will be discussed here. No ditches were identified at Standen during this project.

Magnetometry

There is a smelting workshop ditch in both field 1 and 2 at Chitcombe (fig.8.1). The ditch in field 1 has a magnetism up to 163nT. This ditch forms right-angle with a strong response in the south west corner. The western ditch that heads towards the TWD has a weaker response, and the eastern half of the southern ditch becomes less coherent. The eastern return of the ditch has been lost to the modern day field boundaries. The change in magnetic response throughout this ditch could be down to a number of reasons. One of these could be loss due to modern farming practices such as ploughing. Another could be due to the material that fills the ditch. If areas of the ditch have been intentionally filled with technological waste it would be expected to have a higher magnetism. Moreover, it would be expected to have an uneven magnetism like the TWD.

The ditch forming the smelting workshop in field 2 consists mainly of a linear feature with the returns believed to be obscured by other deposits. The most prominent element of this ditch is the southern side, however even this does not have consistent magnetism with a high of 85nT, reducing to around 10nT in the centre. The western and eastern returns of this ditch are faintly visible on the survey.

As can be seen the two smelting workshop ditches react very differently to the magnetometer survey. The ditch in field 1 being more magnetic and coherent than that in field 2. It is suggested this is due to the material that fills the ditch with field 1 having a higher proportion of technological waste. This could show the treatment of the ditch, with the field 1 ditch being purposefully back-filled, whereas the ditch in field 2 back-filled more naturally through silting up giving a lower magnetic response. The reason for why this might be is unclear.

Earth Resistivity Tomography

The smelting workshop ditch in field 2 at Chitcombe is the only one that was covered by the ERT survey, and appears in lines 10-13, coloured purple in the interpretation in figure 8.18. Lines 10-12 show a much clearer response to the ditch and in all three of these survey lines the ditch presents as a low resistivity feature with lowest readings of 0 Ωm, and around 1m wide at the depth of the archaeology. In all instances the lower resistivity expands with depth into the area that represents the natural geology. This indicates an issue with estimating the depth of the ditch as the fill and the natural have a similar resistivity. Another similarity in all three surveys is increased resistivity anomalies positioned in the near ground surface. In line 10 these measure around 160 Ωm, line 11 between 190-220 Ωm, and line 12 between 260-280 Ωm . It is unclear whether these increased anomalies represent general deposits of material along the ground surface up to the edge of the ditch or if they are a part of the structure of the ditch. With the anomalies existing along a substantial part of the ditch it can be said with higher confidence this is part of the ditch formation. The ditch in line 13 is less clear with the lower resistivity anomaly, marked purple in the interpretation,within the area of the ditch according to the magnetometer survey (fig. 8.1). However, the increased resistivity anomaly to the south is also with the area defined by the magnetometry survey. The lower anomaly was interpreted as the ditch, as that matches the rest of the survey lines across the ditch, but there could be a complete change in deposition in this area and the ditch could now present itself as a high resistivity feature. Only further research would answer this question.

Induced Polarisation

In the IP surveys at Chitcombe, the smelting workshop ditch in field 2 has only been identified in lines 11 and 12 (fig. 8.18). These both show as low reading anomalies but of completely different form. In line 10 there is no recognisable response. However, in the area in which the ditch is present is a large non-responsive area that has been deemed as uncertain archaeology/geology. The ditch could therefore be said to have no response to the IP and is being masked by the surrounding geology. In line 13 there is a large undifferentiated archaeological deposit at 25m descending from the ground surface with low to no response. This is in the same area as a deposit in the ERT survey that could represent the ditch, but more investigation is necessary.

In-phase - Electromagnetic

Both the 15kHz and 3kHz in-phase surveys in Chitcombe field 1 and 2 show responses from the smelting workshop ditch (fig.8.11 and 8.5). In field 1 the ditch has an apparent magnetic susceptibility measuring up to 11500ppm at 15kHz and 8500ppm in the 3kHz and is recorded as anomaly (B) in both surveys (fig 8.19). The reduction in the readings between the two survey frequencies shows the main volume of the ditch is nearer the ground surface. Through excavations it is known that this ditch is 'V' shaped which explains this change in data between the two surveys. The anomaly is biased to the east of the survey and does not extend all the way across, which the ditch does. This therefore more accurately represents a deposit in the ditch rather than the ditch itself.

In field 2 the ditch, which is anomaly (B) in both surveys, has a magnetic susceptibility of up to 7000ppm at 15kHz and 3000ppm at 3kHz (fig 8.19). As in field 1 this reduction in magnetic susceptibility shows that the largest volume of the ditch is nearer the surface, representing a 'V' shaped ditch. The ditch crosses the entire width of the survey area, however the response does not. This shows the fill of the ditch is not homogeneous. This is further shown, using the 15kHz as the example, by the ditch being represented by a number of anomalies of increased polarisation, measuring 6500ppm, on a background of 6000ppm which extends along a portion of the ditch but also beyond it to the north and south.

Quadrature - Electromagnetic

The smelting workshop ditch in Chitcombe field 1 is present in both the 15kHz and 3kHz quadrature surveys as anomaly (B)(fig.8.11 and 8.19). In both cases the area of the ditch is represented by a decreased reading of -20 ppm in the

15kHz and -35 in the 3kHz. In both cases the anomaly extends south from within the location of the ditch south, into an area interpreted to be a working area. To the south of the ditch is a small anomaly of decreased quadrature similar to the ditch. The halo effect of the data is then causing it to look like this anomaly is connected to the ditch, when it is not. In the 15kHz surveys the anomaly within the ditch is biased towards the east of the survey and could be said to more accurately represents a specific deposit rather than the general fill. The 3kHz survey has a similar form of response and has the same interpretations. The smelting workshop ditch in field 2 is not identifiable in the quadrature survey due to a large area of increased conductivity obscuring features.

Discussion

When looking at all the information presented, the different survey types add their own information to the assessment of the smelting workshop ditch. The magnetometer survey allows for the rapid assessment and identification of the feature. The magnetic readings can also give an indication as to the fill in the ditch or preservation. The ERT gives an understanding of the form of the ditch. However, care must be taken as the ditch was made more evident by the increased resistivity of the surrounding area. Without this the ditch has a very similar response to the natural geology so might be lost or mis-interpreted. ERT can also assist and support interpretations drawn from other surveys. An example is that in line 12 at Chitcombe where an anomaly of increased resistivity spreads across the surface of the ditch. This part of the ditch in the magnetometer survey shows increased magnetism. This may then be interpreted as being caused by a cap to the ditch rather than just the ditch fill. IP survey has a similar issue in that the ditch has the same polarisation as the natural geology which means it is lost unless exaggerated by surrounding deposits rather than the ditch fill. The in-phase EM survey allows for the identification of concentrations of material within the ditch rather than the general ditch fill itself as seen in both fields at Chitcombe. The quadrature survey also identifies concentrations of material rather than the ditch fill, but looking at field 2 can be masked by other deposits.

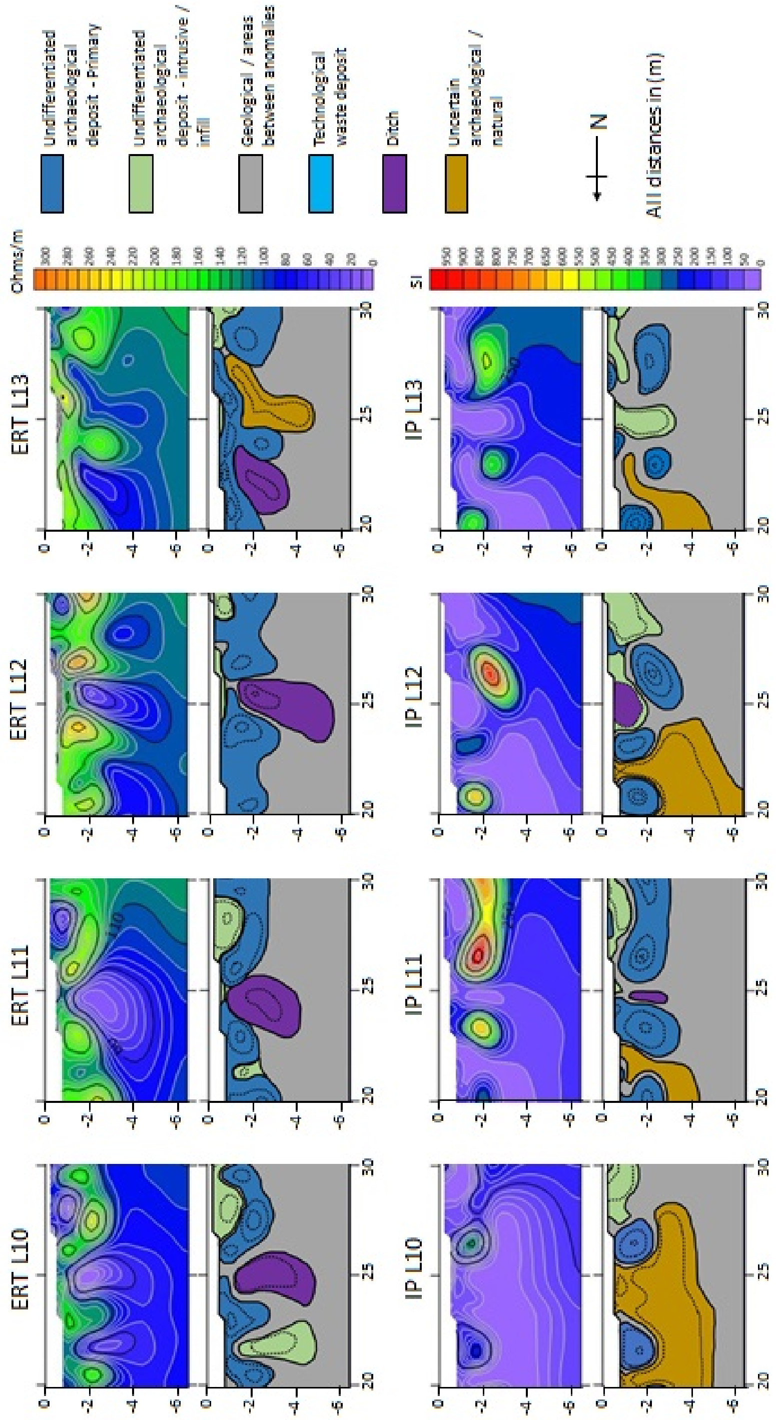


FIGURE 8.18: Composite of ditch response to ERT/IP, normalised and interpreted, Chitcombe L10-13

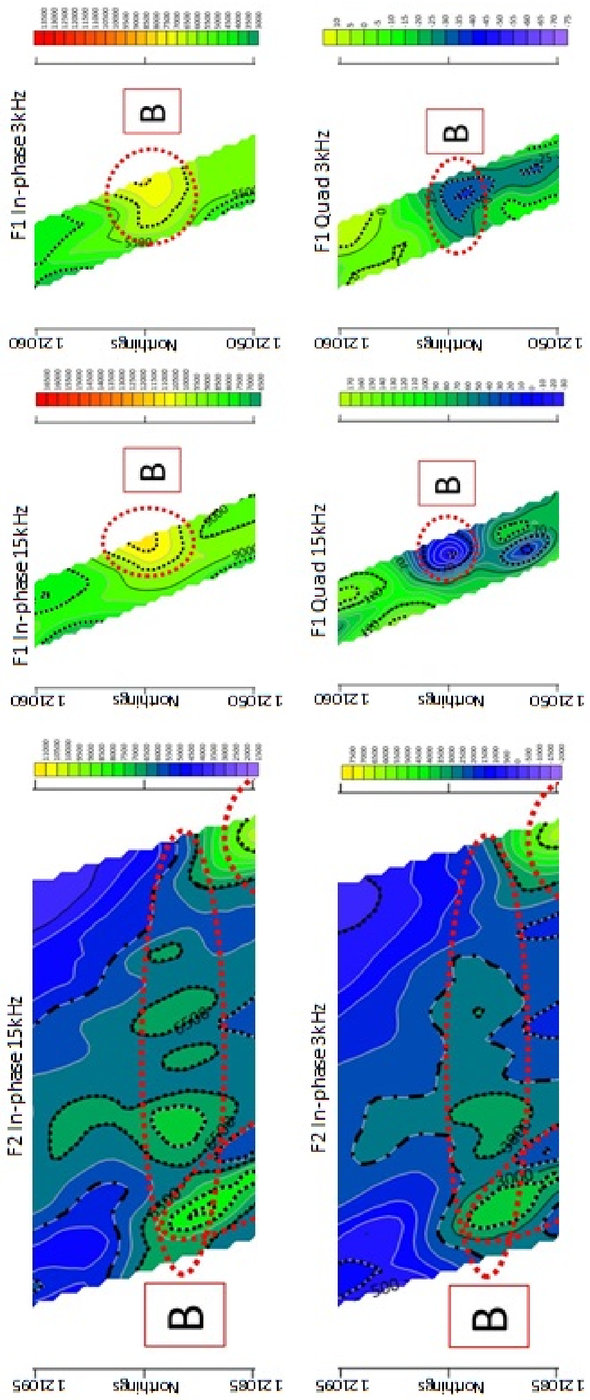


FIGURE 8.19: Composite of ditch response to EM in-phase and quadrature, Chitcombe field 1 and 2

9 Approaches for the investigation of metallurgical sites

9.1 Introduction

So far in this project has set out the 2000 year background to how the Weald was a centre of iron production throughout Britain and Europe, as well as the technical framework of iron production and how this is represented in the archaeological record (Chap.2). A range of approaches for investigating metallurgical sites were then introduced, including site identification, geo-prospection techniques, their scientific framework and possible use in the field being explained; excavation of technological waste deposits; and the sampling and analysis of materials (Chap.3). Two case studies investigating Roman era iron production sites in the Weald were then investigated, Chitcombe (Chap.4 and 5), and Standen (Chap. 6 and 7), with all data-sets presented and discussed with initial interpretations. All the geo-prospection data-sets collected were then analysed to understand key features within the case study sites and a comparisons made between them for a more in-depth interpretation (Chap.8). This chapter will now follow this narrative by considering how the techniques of geo-prospection, excavation, and analysis have been used in the wider archaeological research framework to investigate a variety of sites, including metallurgical types. The aim is to review their effectiveness in the investigation and interpretation of iron production sites to understand if they have assisted in answering the aims of this project which in brief are to understand social organisation, test methods for investigating sites, with focus on technological waste deposits, and to understand the technological waste deposits through the material present.

These will feed into larger discussions in the assessment of iron production sites including the use of a multi-geo-prospection approach to understand features and organisation of sites including the assessment of volumes, the use of spit excavations instead of the more standard stratigraphic excavation in the assessment of technological waste deposits as a form of quantitative sampling, how to classify the technological waste from the smelting process in order to interpret the technological and smelting processes, and the balance of data acquisition verses the time and effort applied throughout all aspects of this project. These discussions and critical reflections will then inform the validity of these approaches in the assessment of iron production sites and how these should be carried forward into future research.

9.2 Geo-prospection: Non-invasive investigation

9.2.1 Magnetometry

In this section the technique of magnetometry will be looked at in the wider aspect of archaeology and how it has been utilised for investigation on other sites. The use of this technique in the field will then be discussed in terms of this project along with wider access the equipment and its validity as a technique in the assessment of iron production sites.

Background

As seen in chapter 3 magnetometry is a technique that detects small anomalies within the earth's magnetic field caused by features within the earth's near ground surface (Gaffney and Gater, 2003). In the 1640's changes in the earth magnetic field were being used to detect bodies of iron ore. The first instruments to more accurately detect these changes were created by the 1870's with vast improvements being made through the 20^{th} and 21^{st} centuries, in many cases due to increased computer power. This technique has the ability to identify such anomalies as areas of burning, ferrous metals, burnt clay, and features such as ditches and pits.

Magnetometry is far reaching in the world of archaeology, being used frequently in both research and commercial investigation. Its primary use is to identify anomalies and features on sites or within landscapes that can be interpreted due to the large amount of expertise and data that is now widely available. A variety of surveys will be discussed as well as this project to see if it adds to the current understanding.

With magnetometry survey being the first step in investigative surveying in both research and commercial situations there is a large amount of grey literature reporting, particularly from the commercial sector, showing the advantages and interpretations of magnetometer surveys.

A survey at Brancaster Roman town shows a detailed plan of a *vicus* beside a Roman fort. This survey picked up a number of ditch features including the defensive ditch around the fort and a pattern of ditches that represent the layout the *vicus*. Track and roadways were also detected. Due to the magnetisation of burnt material, a number of features could be identified such as hypocaust systems and working areas. This is a complex site and was backed up with a GPR survey (Adcock and Gater, 2014).

A further Roman fort and *vicus* was surveyed at Greta Bridge. Within the fort are a number of linear and rectangular negative features. The negative responses are significant as this can be interpreted as stone buildings rather than brick/tile or ditch features. This survey also clearly showed the ditch surrounding the fort as a positive feature (Adcock, 2014).

A survey at Bedford Purlieus shows some of the issues with magnetometer surveys. These include a small research area hampered by thick undergrowth and tree cover and modern metal debris in the topsoil obscuring results (Gater, 2009).

A survey at Sutton Courtenay shows the clear response created in a magnetometer survey to a large ditch feature. This survey shows a number of large ring ditches with a linear ditch dividing the site. A number of other features are identifiable on this site including rectangular features that have been identified as Anglo-Saxon buildings and associated pits (Wood, 2009).

Other larger Roman settlements have been surveyed by Lockyear and Shlasko (2017), Garcia-Garcia et al. (2016), Drahor et al. (2008).

The Hastings Area Archaeological Research Group (HAARG), an amateur research group who have played a large role in this project, have completed a significant number of magnetometry surveys throughout the geographical area of this project and therefore have the most comparable anomalies and features.

Features that have been identified throughout the various HAARG surveys include ditches, trackways, pits, postholes, building foundations, farming practices such as ridge and furrow ploughing, industrial activity, demolition deposits, and modern day pipelines, as well as being able to identify specific types of buildings. These sites across the eastern High Weald include Great Dixter (Cornwell and Cornwell, 2019), Stream Brook (Cornwell, 2014b), Old Place (Cornwell and Cornwell, 2013a), Castle Field (Cornwell and Cornwell, 2016b), Bates Farm (Cornwell, 2014a), and Battle Barn Farm(Cornwell, 2013). Special consideration should be given to St Leonards Church (Cornwell and Cornwell, 2018a) and St Mary's Abbey (Cornwell and Cornwell, 2013b) for the quality of site and response.

Surveys at Castle Field (Cornwell and Cornwell, 2016b) and St Mary's Abbey (Cornwell and Cornwell, 2013b) also show the ability of features to not show up in magnetometry surveys but show clearly in resistivity surveys through the remains of stone foundations that have no magnetic response but increased resistivity.

There are a number of sites that have been surveyed with magnetometry across the east of the High Weald, within the direct landscape of Chitcombe. These sites all show a level of pyrotechnology dating to the Roman period, and are therefore more comparable with this project. These sites include Kitchenham Farm (Cornwell and Cornwell, 2007), Footland Farm (Cornwell, Cornwell, and Padgham, 2013), Castle Croft (Cornwell, Cornwell, and Padgham, 2007), and Northiam (Cornwell and Cornwell, 2017).

The sites at Kitchenham Farm and Footland Farm both have evidence of iron production. These include furnaces, technological waste deposits and a number of other features including possible buildings, ditches, pits and road/trackways. Castle Croft and Northiam are both tile production sites with tile kilns and associated processes, as well as possible buildings, ditches and pits, and road/track-ways features.

All of these studies and previous research have shown in practice how magnetometer surveys can be used and what features and anomalies this type of survey can identify and also what it has the potential to miss or how the data can be obscured under specific conditions. There is also evidence throughout these studies of magnetometry surveys being the first step in a multi-survey approach allowing for a quick interpretation of the site before further surveys are conducted over specific features or anomalies identified by magnetometry. It is also seen in these studies that on many of the sites surveyed there was a level of knowledge of the site and what features and anomalies to expect, enabling for a more accurate interpretation. However, in some cases features and anomalies are identified which are unexpected and can be difficult to interpret accurately. For example, linear magnetic anomalies can sometimes be difficult to distinguish between track-ways and ditches. Also, increased magnetic features that represent burning can have a number of interpretations from furnaces to kilns to ovens which can be difficult to identify without wider understanding.

Application and use within project

There are a number of reasons why this technique was chosen for this project. As has been seen magnetometry is an established practice in archaeology and its ability to detect certain features and responses well understood. Many of these features and responses would be expected to be present on iron production sites. Further reasons include the speed and flexibility of the technique which allows for a birds eye view of the magnetic responses of the site to be mapped allowing for a understanding of the possible organisation of the site and identification of features for further investigation.

An advantage of this type of survey is the relative speed at which it can be undertaken. With sites like Chitcombe consisting of around 120 full and partial 20x20m (ap A.2.1) grids this can be completed by a single person in a week. With additional people to help with the logistics of the survey this could be significantly reduced. Sites the size of Standen (ap C.2.1), are able to be surveyed by a single individual within a day if all on open grass or slightly longer if survey within woodland is necessary. As before if more people are available to assist with logistics then this time can be reduced. In the future, with this relative speed, a project could be undertaken to magnetically map a number of these iron production sites in a short period of time with minimal resources that are relatively easily attained.

A second advantage to this type of survey, and specifically the GRAD-601 twin probe (other machines can probably do the same), is the flexibility with which it can be used. The first use of this flexibility is the ability to complete partial grids enabling the complete coverage of a site. The second is that the size of grid can be altered depending on the vegetation coverage. In this project, grid sizing was changed from 20x20m in open field to 10x10m in woodland.

Another advantage is being able to change the transect and data intervals. This gives fast lower resolution scanning surveys to identify primary areas of interest and higher resolution surveys over these areas to pick up clearer details of features. The data can also be collect in a scanning mode, where the data is collected automatically at set time intervals, or manually where a button in pressed to collect the data at a specific point. This enables fast continuous surveying in open field sites with no obstacles or on a point by point approach in woodland or areas with multiple obstacles.

Finally the data range can be altered on the machine itself allowing for detection up to 1000nt. This is important on iron production sites as the magnetism frequently surpasses 100nt which is the standard setting for archaeology.

Care has to be taken with this technique and the interference from modern iron debris. This includes such things as fences, gateways and debris on the ground such as farming waste including objects such as horseshoes. In many cases these are above ground and are visible enough to avoid during surveys but some can be buried and not obvious, such as modern pipes. These high iron anomalies can cause such strong responses that they can obscure archaeological features. To negate many of these the site should be walked and checked to remove or avoid as many as possible.

When the Bartington GRAD-601 is set up it has to be initialised and 'zeroed'. This is completed by finding an area where the magnetism is consistent and low. This can be difficult on sites of iron production where there is increased magnetism spread across the site.

With the technique being so widespread across archaeology, the equipment to carry out these surveys is also readily available. Companies, academic institutions, and amateur archaeology societies own these machines with the knowledge and skill of how to use them and process and interpret the data. In many cases this equipment could be organised to be used for free or at a very low cost which therefore makes it highly accessible for use.

Assessment of value of the technique

High magnetism on iron production sites can be both a blessing and a curse. Some features such as furnaces are clear and recognisable from the survey results. Moreover, with magnetic debris from the waste products of smelting being spread over the site this can enhance features such as ditches and pits.

The flip side of that advantage is that with such high magnetism spread around it becomes easy for areas to be overrun and 'messy' in the results, obscuring anomalies or features that may exist. This also means that care should be taken in the interpretation of iron production sites particularly when assessing the waste deposits. With modern ploughing and re-use of waste products for road making, and secondary uses in antiquity of the waste products for hard standings and track or road building, magnetometer survey cannot and should not be used for assessing the lateral extent of the waste deposits but can be used to give a rough understanding.

With the use of magnetometer surveys being widespread certain types of features are well recorded. However, iron production sites have some specific features and materials which may make interpretation and terminology important. An example of this is the difficulty in the interpretation between a ditch which may contain slag and a track way that may also contain slag. With no true three dimensional information it can be very difficult to tell the difference between these types of features. The most important and believed to be easily identifiable feature on iron production sites are the furnaces. These give a very high magnetic response and tend to be in a circular form. However, care must be taken as there is potentially a number of different processes within these sites that could create features that give similar responses.

Therefore, it is clear that magnetometer surveys should always be used in the primary assessment of iron production sites to understand the layout of features and anomalies across a site, and guiding a program of more intense, high resolution surveys to be targeted and completed. It also enables surveys to be completed in part through woodland. Although this process is slower than in open fields it is very important to complete and should not be missed or ignored just because it is 'harder'. Large areas of the Weald are covered in woodland and iron production sites tend to fall within or partly within woodland areas. Therefore, by neglecting these areas an important part of the evidence is being knowingly missed.

9.2.2 Earth Resistivity Tomography

In this section the technique of Earth Resistivity Tomography (ERT) will be considered in in the wider field of archaeology and how it has been utilised for investigation on other sites. The use of this technique in the field will be discussed in terms of this project along with wider access to the equipment and its validity as a technique in the assessment of iron production sites.

Background

As seen in section 3.2.2 ERT is a technique that measures the change in resistivity within the near earth's surface by passing a current between two electrodes. This survey type originates in the discipline of geology and geography in the early 20^{th} century, with major advancements occurring from the 1970's with increased computer processing power. This technique has the ability to identify such features as walls, stone/tile work, or large deposits of increased resistivity materials, as well as ditches, pits, and grave cuts.

While resistivity surveys are commonly used in archaeology to produce a two dimension horizontal view of the resistivity of the near ground surface ERT is a technique that has been used less frequently and more in a research capacity rather than standard commercial practice. These projects will be discussed to see what was identified and if this current project adds to the current data.

One application of ERT survey is to track features and see how their form changes. This has been shown in a study by Tsokas et al. (2014) where a Roman road was traced through the landscape, showing its change in shape and resistivity giving an understanding of its buried structure in both the horizontal and vertical planes. ERT can also be used to create accurate three dimensional reconstructions of buried structures. An example of this can be seen in Maio, Manna, and Piegari (2016) where a building wall has been mapped in three dimensions allowing for an accurate assessment of its location below the ground surface. ERT has been used by Meyer, Ullrich, and Barlieb (2007) to map the vertical and horizontal extent of a smelting slag heap as well as identifying a number of other features including pits and walls at the Roman site of Munigua in Spain. ERT has also been successfully used on the multi-period multi-layer site of Old Smyrna Hoyuk, in Turkey (Berge and Drahor, 2011a,b). This study proved the ability to distinguish different layers within multilayered archaeology to give an understanding of building and deposits of a city revealing contexts before excavation.

At Meroe in Sudan ERT has been used with great success (Humphris and Carey, 2016) where a number of survey lines were completed across a smelting waste heap. This project showed the ability of ERT surveys to identify the response of archaeometallurgical deposits, archaeological debris and structures within the smelting waste heap. This project also sets a precedence for this technique for not only identifying the shape of smelting waste deposits but for differentiating structures and changes within a waste deposit.

The studies above have shown in practice how ERT surveys can be used to investigate archaeological sites and features and the types of features and anomalies that detect. It has been seen in many of these studies that ERT is a secondary survey tool, being used to investigate an anomaly or feature that has been previously identified by other means including survey types such as magnetometry or standard resistivity or by physically being identified in the landscape. A feature of this survey type that assists archaeologists the most in their interpretation and investigations of sites is the ability to measure the depth of features. This allows for a greater ability to plan further investigations. Beyond just giving a depth of feature/anomaly ERT has shown the ability to map a feature in three dimensions giving a depth, width, and height of a feature and a better understanding of its overall form. If multiple lines are surveyed along a feature this then creates the possibility of tracking the feature calculating changes in its form and when compiled can begin to give an estimation of the volume of the feature. ERT has also been shown to have the ability to not only identify features and anomalies but also separate these out on complex sites with multi-layer stratigraphy giving a better understanding and interpretation before further investigation.

Application and use within the project

There are a number of reasons why this technique was chosen for this project. As has been seen resistivity is an established practice in archaeology but using a form that produces a birds-eye view plan rather than vertical slices through the near surface. However, due to its common use its ability to detect certain feature and responses is well understood. A number of these features and anomalies would be expected on iron production sites and are therefore a reason this technique was chosen. One of the aims of this project was to test methods for understanding features on iron production sites including assessment of the volume of technological waste deposits. The main reason for choosing ERT was to assist in addressing this aim with the ability to detect and assess the depth of the technological waste deposits.

This survey type is very slow with a single line taking an hour or more to complete with a team of three people. Therefore, if this survey type is available for use it should be done after initial surveys, such as magnetometry or resistivity, in order to focus on specific anomalies which may warrant further investigation.

There are a number of different elements to the equipment needed for ERT, including 64 metal electrodes, two large wheels of cables capable of each extending over a minimum of 32m, as well as the main control system. All these parts can be heavy and cumbersome meaning a single person on a secluded site would find it difficult to transport all the equipment to where it is needed. This would become easier with more people.

Earth Resistivity Tomography has some flexibility in its ability to investigate sites and features in that the spacing between the electrode can be changed. If the depth of the site is unknown then a wider spacing allows for deeper penetration into the ground, giving more complete coverage. If the depth is known then the electrodes can be placed closer together giving a shallow survey depth with an increase in resolution.

If the site being investigated is under dense bush or woodland, this could cause an issue with ERT. All the electrodes have to be placed in a straight line, therefore any obstacles can become an issue. This problem arose at both Chitcombe and Standen. At Chitcombe this could not be overcome. However, at Standen there was a small enough hole in the hedge for the line to pass through and small trees and fences were luckily positioned between the electrodes meaning slack in the cable could be used to go around the obstacles without breaking the line of the electrodes.

As with any resistivity survey using electrodes placed in the ground, weather and climate conditions can affect this survey type. If this survey is completed at the end of a long dry summer then there might be issues with data collection due to the high resistance caused by the dry natural, which is a possibility in the clays of the Weald. Therefore, it would be prudent to chose a time of year when the ground is going to contain some moisture, giving better data collection and also for ease of positioning the electrodes.

The equipment needed for this type of survey is highly specialised being held by such large institutions such as the Camborne School of Mines. The equipment is therefore more difficult to acquire for investigation, but not impossible.

Assessment of value of the technique

Earth Resistivity Tomography was shown to be of use in this project in a number of ways. It has shown the ability to inform on the depth of deposits and if there are any changes within the deposit. It has also shown the ability to inform on the vertical section and therefore structure of possible features, as seen with the cross section of the furnace. This can enable better planning for further investigation and give information on possible levels of preservation.

In the assessment of the volume of technological waste deposits Earth Resistivity Tomography showed potential in this project as well as others discussed. One issue with ERT is the accuracy of the interpretation of the true edge of features such as the TWD to give an accurate volume. Moreover, the technological waste deposits in the Weald are unlike those seen in Sudan (Humphris and Carey, 2016) or Denmark (Rundberget, 2017). In these latter cases the waste deposits exist as heaps on a relatively flat natural landscape. However, in the Weald the waste deposits are spread along the side of ghylls which are not flat in their form. Hence, to calculate the volume of these deposits a number of lines would need to be completed along their lengths, and when some of these such as at Chitcombe extend for hundreds of metres this would be a very long and expensive task. However, over time with a number of surveys completed a better understanding of average depths and formation can be gained.

The use of ERT as a tool for investigating iron production sites has shown may strengths with one major, yet easily correctable, weakness. This weakness is that there is not as yet an established data set and research into the use of this technique on iron production sites to truly understand responses and features. However, the data that was collected in this project along with the other studies discussed, sets a strong precedence for its continued use.

ERT has shown through this study to be able to assess the depth, shape and position of the waste deposits. It has also shown its ability to give an understanding of other features such as ditches, pits, post holes and furnaces (ap A.2.2). However, with iron production sites being complex in their nature, with limited understanding of their overall layout and structure, there are many features in the surveys that need further investigation to define them and a set of controlled experiments on specific materials to better understand their particular responses for greater interpretation.

9.2.3 Induced Polarisation

In this section the technique of Induced Polarisation will be looked at in terms of its wider use in archaeology and how it has been utilised for investigation on other sites. The use of this technique in the field will then be discussed in terms of this project along with wider access to the equipment and its validity as a technique in the assessment of iron production sites.

Background

As seen in section 3.2.3 Induced Polarisation is a technique that detects the charge decay of the overvoltage of material within the earth's near ground surface. The technique began in the early 20^{th} century but made advances in the 1940's due to its military applications for the detection of mines, and then again in the 1970's with increased computer power and its application in the petroleum industry. Due to the rare use of this technique in archaeology there is not a comprehensive list of features and anomalies that can be identified.

Induced Polarisation has been used very infrequently on archaeological sites and often with little success (Gaffney and Gater, 2003 53) always being as part of research rather than in a commercial application. The projects in which Induced Polarisation has been used will be discussed as well as examples from its use outside of archaeology. This project will be discussed to see if it adds to the current data on the use of this technique in archaeological research.

Two studies have used Induced Polarisation to investigate iron production sites. The first is a project by Florsch et al. (2011) that used the technique with some success in evaluating the quantitative characterisation of a slag heap. This was also backed up by laboratory calibrations allowing for new opportunities in quantifying scrap resulting from metallurgical production.

The second is a project by Meyer, Ullrich, and Barlieb (2007) at Munigua in Spain. This study showed the ability of Induced Polarisation to investigate the vertical and horizontal extent of the slag mounds as well as other features such as pits which contained slag as a fill. Induced Polarisation can also be used to identify different features on sites as shown in the study by Schleifer et al. (2002) in which a Bronze Age plankway was detected and traced through bog-land showing the ability of this technique to detect specific materials.

These studies have shown in practice how Induced Polarisation surveys can be used to investigate archaeological sites and features and the possible types of features and anomalies IP can detect. Induced Polarisation is most often used as a secondary survey technique to investigate an anomaly or a feature that has been previously identified by other means such as magnetometry or resistivity or by physical identification in the landscape. Induced Polarisation also has the ability to identify specific materials, leading to a more accurate interpretation of what is forming a deposit. Induced Polarisation can also reveal the depth at which a feature is located within the ground as well as the physical width and height of the feature itself giving an understanding of its overall form. If multiple lines are surveyed along a feature this then gives the potential to track the feature calculating changes in its form and when compiled can begin to give an estimation of the volume of the feature.

Application and use within the project

There are a number of reasons why this technique was chosen for this project. As has been seen the use of Induced Polarisation in archaeology is rare. However, its use here assists in meeting the aim to test a number of techniques for better understanding features on iron production sites including the assessment of the volume of technological waste deposits. Due to its use in the mining sector for identifying ores, including those of iron, this technique was chosen for this project for its potential ability to identify specific materials and their occurrence within the site. Another reason for choosing Induced Polarisation is its potential to answer the aims of assessing the volume of the technological waste deposit as the survey measures responses in a vertical section through the near surface.

The one advantage of this survey type is, as has been seen in section 3.2.3, that the data is collected simultaneously with the ERT survey. Therefore, any time the ERT surveys are completed induced polarisation data should also be collected as this only adds a nominal amount of time in the field, and the standard time in post processing. Moreover, with Induced Polarisation data being collected by the same equipment as the ERT survey the same in field constraints apply to IP.

Just like the ERT survey, IP is infrequently used on archaeological sites and is highly specialised. Therefore, there is little comparable information or established datasets and the equipment could be hard to obtain.

Assessment of value of technique

It is clear from the surveys carried out in this project that Induced Polarisation as a technique is of some use in investigating iron production sites as the majority of responses in the surveys were within the areas where archaeological deposits were expected (ap A.2.3). These responses often did not form specific features showing that Induced Polarisation informs more on specific material that form deposits rather than identification of the shape and size of the feature. Therefore, Induced Polarisation is validated in adding a more specific layer of understanding to the data-sets, possibly identifying specific practices when used in conjunction with other survey types such as ERT, but is probably not a valid technique on its own.

However, this project shows this technique is valid as an investigation tool on iron production sites, and therefore should be used in the future to build up a larger data set and a better understanding and interpretation of the data.

9.2.4 Electromagnetic Surveys

In this section the technique of Electromagnetic surveys will be looked at in terms of its wider use in archaeology and how it has been utilised. The use of this technique in the field will be discussed in terms of this project along with wider access to the equipment and its validity as a technique in the assessment of iron production sites.

Background

An introduction in section 3.2.4 Electromagnetic (EM) techniques can detect anomalies due to their physical properties depending on the type of survey being used. In-phase EM can be used to detect changes in the magnetic susceptibility of the near earth's surface, and quadrature EM can detect changes in the conductivity of the near earth's surface. These survey types were developed in the second half of the 20^{th} century in the petroleum and mining industries. Their use then spread to the environmental sector and beyond in the late 20^{th} century. The in-phase EM portion of this technique can detect anomalies including areas of burning, ferrous material, ditches, and pits. The quadrature EM portion of this technique can detect anomalies including walls, stone/tile, ditches, pits, and any anomalies with a contrast in conductivity with its neighbouring material.

Electromagnetic surveys are not commonly used in archaeology and tend to be used in research rather than the commercial archaeology. The uses of this technique will be discussed followed by its use in this project and whether it has added to the current data on this technique in archaeological research.

A project by Maio, Manna, and Piegari (2016) at Phaistos, Crete, has shown the uses of EM surveys at multiple frequencies using both in-phase and quadrature to identify structural remains. The data gained showed the magnetic field response of a wall and its conductivity response at 5kHz, 10kHz, and 15kHz showing its potential change with depth.

A study by Dabas et al. (2016) also shows the ability for EM surveys to detect stone built walls, particularly in the quadrature response, as well as giving an estimation of the volume of the archaeological deposit.

A study by Ullrich et al. (2016) shows an advantage of using EM survey, particularly the in-phase response to identify metal object s that may be of a modern origin as they are nearer to the ground surface.

Another study by Welham et al. (2014) has shown the ability for EM surveys to identify the remains of wattle and daub structures, possible well or latrine features, as well as a smithing area.

And a study by Saey et al. (2013) has shown the ability of EM surveys to identify features in a WW1 battlefield remains that could not be identified by aerial photography or other geo-prospection techniques due to a low contrast with the natural geology.

A study by Bonsall et al. (2013) shows the benefits and advantages of using an EM machine that allows for the detection of multiple depths of the same volume of earth in both in-phase and quadrature as opposed to single depth machine types.

Two studies, one by Lockyear and Shlasko (2017) and one by Gater (2009) use the response of magnetic susceptibility to identify specific areas of burning.

These studies have shown in practice how EM surveys can be used to investigate archaeological sites and features and the possible types of features and anomalies EM can detect. A number of these studies have shown that EM surveys can collect multiple data-sets simultaneously including in-phase and quadrature, informing on both magnetic susceptibility and conductivity. This allows for a direct comparison between these datasets giving a more in depth understanding of features and anomalies. It has also be shown that with the capacity for multiple frequencies to be used at the same time or different coil orientation, can inform on the depth of features and its change in form. This could then begin to enable an understanding of the volume of a deposit. This also allows for the separation of modern day metallic inclusions in the topsoil which could obscure archaeological deposits below. It has also been seen in these studies that EM surveys have finer sensitivity to changes in magnetic susceptibility and conductivity than the standard magnetometer and resistivity surveys that are more commonly used. This means that a greater number of features and anomalies could be detected and hence interpreted.

Application and use within project

There are a number of reasons as to why this technique was chosen for this project. One is the flexibility of this technique to investigate the site at a variety of depths while detecting different physical properties, which helps to address the aim of understanding the organisation of iron production sites. It is also a technique whose use is becoming more common in archaeology with more features and responses being understood. However, it has not been used to assess iron production sites in the way it has been applied in this project and therefore was chosen to meet the aim of testing methods for understanding features on iron production sites including assessment of the volume of technological waste deposits.

The time it takes to complete this survey type is somewhere between a magnetometer survey and a standard resistivity survey depending on the set up of the machine as it is flexible in its settings allowing for scanning recording or point-by-point manual recording of data. Therefore, this technique could be used for either site wide scanning surveys or more high resolution surveys over specific anomalies. The technicality that makes this survey particularly fast is its data collection, as has been seen in section 3.2.4, it can collect multiple data sets at once. In this project four were collected but more was possible. These include in-phase and quadrature at a number of different frequencies, in this project 3kHz and 15kHz.

Another advantage, particularly with the machine used here, was that survey grids can be set to any size as needed. This means that anomalies can be targeted more precisely making the higher resolution surveys more efficient.

The ability for this technique to be used at differing frequencies allows for investigations of differing depths. As explained in section 3.2.4 the depths are not exact measurements but can be seen as being below or above differing frequencies and the results are an average from the entire area at that survey point. However, this does allow for understanding of the form of features in both the vertical and horizontal plane and if the archaeological deposits on a site are known to be deeper or shallower this can be catered for within the survey. It can also allow for the identification of more modern metal deposits in the ground surface that may be masking archaeological deposits

With this survey type not being commonly used in archaeology it could be difficult to access for research. However, there are a number of different machines that can be used for this type of survey which are held at a number of institutions and commercial companies and can be acquired at a cost or as part of a robust research project.

Assessment of value of the technique

EM surveys have shown to be valid in their application in investigating iron production sites.

Through the theory of electromagnetism the electrical and magnetic properties of a material are connected. This survey then has the advantage of being able to inform both the magnetic, in-phase, and electrical, quadrature, properties of materials at the same time enabling a direct comparison between two properties. The fact that both of these properties are recorded also gives the opportunity to compare these results with a number of other survey types including magnetometry and resistivity to gain a thorough understanding of the properties of an anomaly.

Due to the nuances of information recorded this technique should not be used to replace the traditional magnetometry and resistivity surveys. EM techniques add a new level of information technically measuring magnetic susceptibility and conductivity. This survey type also is not as widely used in archaeological research compared to the more standard magnetometry and resistivity surveys, therefore the data from these surveys is less well understood. However, the ability to investigate different aspects of magnetism and electrical response can inform more specifically the potential materials forming features, which were seen in the furnaces at Chitcombe where examples containing elevated amounts of iron ore had a much higher in-phase responses than other furnaces that were not readily identifiable as they had a similar in-phase responses to the surrounding material.

With the ability to investigate using different frequencies, changes in features can be understood in both the vertical and horizontal planes. These are not specific depths but can give an understanding for further investigation. It can also be used to understand whether anomalies are more likely to be modern deposits in the topsoil or archaeological deposits at depth.

Because of the way the data is collected as an average of the volume of the ground there is a chance that anomalies could become masked by other material in that volume, potentially leading to the loss of information. This could become a particular issue on iron production sites where large volumes of waste material have the potential to have been spread across a site masking features.

It is therefore clear that this technique is in the early stages of development in archaeology but shows great potential. Allowing for the collection of multiple datasets including various depths within a single survey.

9.2.5 Reflection on choices made

Geo-prospection surveys were used in this project to try to answer two of the main project aims. In brief these were to understand the organisation of iron production on an inter- and intra- site level and to test methods for investigating the volume of the technological waste deposits. Reflection on the choices made as to the survey types used to answer these aims will be discussed.

Organisation of iron production sites

It is believed that all survey choices made in this project to understand the organisation of iron production at a site level and landscape level have been justified in their initial assessment. It is clear that magnetometry should be the first survey completed on any iron production site to give an initial understanding of the wider site and features, and if this is the only survey type available, can be sufficient on its own for a preliminary assessment. This is due to the ability of this survey type to identify important features on iron production sites which help understand organisation, including furnaces, buildings, and ditches, and larger conjoined features such as smelting workshops which signify an industrially-organised site. This can then be followed with more targeted surveys over areas of interest with techniques such as EM which has potential for understanding the relative depth of features as well as some of their physical aspects. At this point it would also be the recommendation from lessons learned in this project to include a resistivity survey using the standard equipment commonly seen in archaeology where a birds eye plan of the change in resistivity is recorded, to assess more specific areas as it is believed this could help to identify more features and could help to 'see through' messy magnetic areas that may be obscuring data. Earth Resistivity Tomography and Induced Polarisation should only be used where it answers very specific research questions and aims as it is a large investment of time and effort.

Volume estimation of technological waste deposits

A number of studies have investigated calculating the volume of the technological waste on iron production sites using a variety of techniques.

Investigation at Meroe, Sudan (Humphris and Carey, 2016) used three methods to calculate the volume of technological waste deposits. These were electrical resistivity modelling, excavation modelling and surface survey modelling. All three of these gave different estimations of the density of total archaeometallurgical material.

Investigation into iron production in southeast Norway has attempted to calculate the volume of slag heaps in a number of different ways. One of these was the complete excavation of a slag heap. This approach was shown to be the most accurate but extremely resource heavy, and unpractical. Another way was by producing a 3D topographical plan of the surface of the slag heap after de-turfing, and then a 3D model of the ground surface after the removal of the slag heap. These models were then joined and a volume calculated. This approach was seen as reliable, however even small errors in definition lead to large margins of error in calculation. Another approach taken was by mathematical calculation by estimating the shape of the slag heap (Rundberget, 2017).

The Romano-British iron production sites of the Weald have been grouped according to their volumes (Hodgkinson, 1999). These volumes have been calculated using to up to three physical measurements of dimension. In some cases all three measurements are known and in some cases none are known but personal knowledge and comparisons have been used. Although this approach can be used to roughly group sites it will have a large degree of error.

The ability to calculate an accurate volume of the technological waste deposits of an iron production site is fraught with difficulties and inaccuracies. Many of the scenarios which cause these difficulties are present in the Weald. The first of these is that the technological waste deposits are positioned along ghyll-sides and on slopes making the interpretation of the depth problematic as the topography of the underlying natural ground surface is unknown as the ghyll-sides are not uniform in their nature. Moreover, the surface of these deposits is often covered with a layer of topsoil that has built up over time since deposition. Therefore, an accurate topographical model cannot readily be made of the deposits as their true surface and base is not accessible. Because of this practice of deposition down ghyll-sides the lateral extent of a waste deposit can become elongated running along the bank rather than a clearly defined heap. As was seen at Chitcombe (Chap 4) this has led to a technological waste deposit that extends for a couple of hundred metres. It becomes a near impossible task to survey the whole length of the deposit to understand its changing form. Throughout the Weald, technological waste has been quarried and removed from iron production sites to be used as road and track making material up to the modern day. Therefore, a true volume of the waste deposit cannot be calculated on sites where this has occurred as all the material is not present to do so making calculations and interpretations wrong.

The use of Earth Resistivity Tomography and Induced Polarisation on these sites to assess the technological waste deposits has shown potential in its application meeting the aim of testing techniques for investigating the volume of these features. However, due to the nature of these deposits in the Weald it can be seen that this is a complex task which needs further work and development in the future.

9.3 Assessment of excavation strategy

Spit excavation

The decision was made early on in the planning process of this project to excavate through the technological waste deposit in spits rather than the standard stratigraphic excavation due to this method being successfully used to investigate other technological waste deposits including Juleff's work investigating the early iron and steel in Sri Lanka (Juleff, 1998), as well as the work undertaken at the Royal city of Meroe, Sudan (Humphris and Carey, 2016). Due to the technique of excavating by spits rather than stratigraphically being non-standard in British archaeology it will be discussed in more depth here.

The technique of excavating by spits rather than stratigraphy is not the standard practice within UK archaeology, often omitted from discussions in textbooks on archaeological practices. This is demonstrated by its absence in key sources such as Archaeology Theories, Methods and Practice (Renfrew and P, 2008).

A number of discussions have taken place on the use of spit excavation. Its use was critically dismissed by Wheeler where he argues it would lead to the loss of stratigraphic information which could cause a miss-representation of artefacts discovered (Wheeler, 1954 6). Both Barker (1993) and Roskams (2001) argue that this technique should only be used where there is no stratigraphy present or there are large volumes of the same material, for instance sand. Further adding to Wheeler's argument that important stratigraphy could be lost. Rahtz (1996) discusses this technique after its use to excavated burials in sand where there was little hope of finding preserved remains. Rahtz concludes that this is a viable technique to use, but only under specific conditions used to answer a specific aim.

It can be seen that it is fairly well agreed that to excavate through a complex archaeological site with multiple phases and complex stratigraphy using spit excavation would lead to a loss of information and probable misinterpretation. However, it has been seen that in certain circumstances and to investigate specific aims this approach can be valid.

Application and use within this project

This project had a specific aim to quantify and characterise technological waste from iron smelting. For a number of reason the use of spit excavation was deemed to be the most effective approach with which to collect the materials for creating datasets to answer the aim.

One reason for using spit excavations is based on its successful use in other projects (Juleff 1998, and Humphris and Carey 2016) where material was collected to be quantified and classified. It was also made clear through discussions with Juleff, who has a large amount of experience excavating iron production sites. This point was confirmed through this project, particularly at Standen, where there was no distinct change in stratigraphy throughout trench 1.

A standardised approach to the collection of material was needed to create datasets that could be quantified and classified while being comparable within and between trenches. Spit excavations allow for this as a set volume of material can be maintained. It was decided in this project that spit depths of 0.1m would be used. This depth was a balance between the size of fragments within the deposit, so they did not penetrate between two spits, and the resolution of data that could be gained. This was the smallest applicable spit depth which gave the highest resolution, which was hoped would pick up finer detail in changes of material and therefore processes and actions.

Although the use of spit excavation created a standard practice it allowed for a certain amount of flexibility within this standard with the ability to change the depth of the spit depending on a number of factors such as size of inclusions, research questions and time/resources available.

9.4 Assessment of material collection

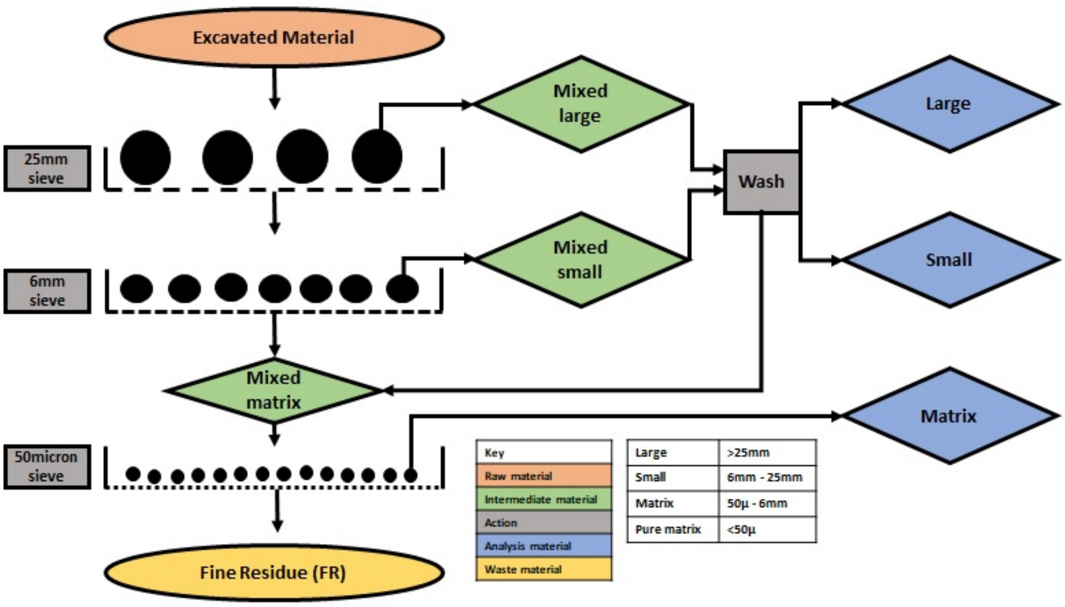


FIGURE 9.1: Material schematic

In this project a standardised strategy was created for the collection of material based on size (fig 9.1), which could then be further divided and investigated by such aspects as material type. This was designed to be flexible to adapt to particular local circumstances while capturing data in a comprehensive, consistent, and comparable manner. This strategy will be discussed and assessed here step by step.

<u>Sieving</u>

Three sieves were used in this project. Two (25mm and 6mm) to separate out the three material groups; 'mixed large', 'mixed small', and 'mixed matrix', and one (50μ) to wash the mixed matrix to create fine residue.

The use of a sieve was seen as a means to make the sorting and weighing of the excavated material more efficient and standardised, compared to sorting material by eye. To further this efficiency the sieves were custom built for this project allowing up to 15kg of excavated material to be sieved at a time.

The material used to build the sieve, particularly the mesh material itself, had to be extremely hard wearing as the mechanical process of sieving and the toughness of some of the technological waste could lead to breakages of the equipment. To begin with only 6mm mesh of an appropriate standard could be found which dictated the grading size. When it became evident through observations made during fieldwork that a larger grade sieve was needed this had to be specifically sourced.

A number of potential issues arose while using the sieves. The first was the breakage of some of the more friable material such as burnt clay. Although this was noted on a number of occasions it was believed to be within a acceptable limit that did not change the datasets. The second was due to the variety of shapes for example elongated fragment that has a length of 50mm and cross section of 2mm could end up in the mixed small as it passes through the sieve length ways. This was observed during sieving and efforts made to return the material to its appropriate size category. The third was the efficiency of sieving which was occasionally hampered by wet weather which caused all material to bind together with clay making it difficult to pass through the sieve.

Mixed materials

The mixed materials are an important intermediate step in the process which needs to be weighed in order to understand the total materials within the trench. When the mixed large and mixed small categories are washed material will be lost. This material is believed to represent mixed matrix that has adhered to the larger fragments. The weighing of the mixed large and small categories then allows for a calculation of the loss of this material when washing. In this project this weight was then used in the extrapolation of the 'Matrix' category by giving a total mixed matrix weight.

Due to the large amount of material during excavation and the time versus information gained, the whole of the mixed large was collected and a sub-samples of the mixed small and mixed matrix. In ideal circumstances all the material would have been collected but this was not viable.

Washing

As has been discussed in previous chapters the washing of the material was a laborious and time consuming task, but one that was necessary in order to expose the detail of the material used for classification, as well as gaining a more accurate representation of the weights of material.

Final material

The final materials created were Large, Small, Matrix, and Fine Residue. Although the size categories were defined by the availability of appropriate sieve mesh they have been shown through this project to be appropriate size categories. The large material had the highest abundance within the trench and sizes above 25mm allowed for identification of textures and identifiers used for the classification.

The small and matrix categories were not used for classification so comments cannot be made on their viability for this purpose. However, the separation of these sizes has showed some interesting trends in the data across the two case studies when material types are identified.

Critical reflection

The question should be raised here as to the amount of material that is needed to understand these waste deposits against time and resources. In the perfect world the entire deposit would be excavated, recorded, and analysed. However, this would be unrealistic. On the other hand, this project saw relatively small trenches placed within the waste deposits, and while intensively analysed within themselves they form a very small part of the waste deposit, but this is what time and resources allowed within this project. In the future it is hoped with larger projects a greater extent of the technological waste deposits can be excavated and sampled, and if this approach is continued on a large number of sites, even on the small scale seen on this project, the larger combined data sets will give a more detailed interpretation.

It tends to be interpreted that the oldest deposits within the technological waste deposits are at the bottom and the newest at the top. In some sense this has to be true as standard depositing of material would dictate that newer material would end up on top of older material. The only possibilities where this would not be the case is if an older deposit has collapsed on top of a newer deposit or if the deposit has been altered at some point by moving older material on top of newer material. Both of these scenarios are possible but would be impossible to see in a small trench, such as excavated in this project, if possible at all. The stance has been taken that the technological waste deposits show a movement through time with the lower levels being the oldest and the upper levels the newest. However, it is not being taken as fact that this movement through time is linear, showing that the spits and contexts cannot be guaranteed to be connected by time With this said, by comparing the percentage weight of types within the same spit it can be understood how the types are associated with each other and how this association changes throughout time, even if this is not strictly linear.

It should be noted here that the real world reality of excavating through, sorting and collecting material, and preparation for analysis of technological waste is extremely physical and time consuming work. As has been seen this involves the systematic excavation of tonnes of material being removed from the trench and then weighed and sieved multiple times. This material then needs to be removed from the site and washed to gather more accurate weight measurements and to uncover features that are used to classify the samples. It took a single individual of athletic stature and above average fitness a week and a half to complete a trench 1x1x2m deep, in the case of Chitcombe. At Standen there were a number of volunteers to help which spread the physicality of the workload but maintained a similar pace. Moreover, due to the clay that is the natural geology throughout the Weald mean that the washing of samples has to be done with water and a brush on each individual piece as this is the only way to remove the clay to a satisfactory level.

9.5 Quantification and classification

The use of sub-samples in this project of the mixed small and mixed matrix meant that the data had to be extrapolated to assess the spits and trench as a whole. It is clear there is going to be a margin of error within this as the calculation is based on a small amount of data from a heterogeneous deposit. However, this margin of error is a trade off against time and resources and has not been seen to negatively influence the data in this project.

When classifying an attempt was made to take as non-biased an approach as possible. This was to try and identify the full range of possible types rather than force samples into pre-determined groups. As seen through this project there has been a level of success with the identification of a number of dominant and non-dominant types which have individually or as groups clearly informed on the processes and actions occurring on the iron production sites

This approach still needs to be developed in the future for the allowance of in-depth statistical analysis. Although a number of data points were collected on each type they were not done so with a particular statistical investigation in mind which means data might not be recorded in the most appropriate manner. In the future the datapoints to be recorded should be pre-determined to allow for the most coherent data to be collected but the types should not be pre-determined allowing for the identification of the full range present.

9.6 Conclusions

Survey

As has been discussed, all the survey types used in this project have been shown to be valid in their application to the investigation of iron production sites, and on top of previous research continue to set a precedence for their future use.

What has been made evident is that for a thorough investigation of iron production sites a number of geo-prospection surveys types should be used, not just a single type. It has been shown that magnetometry should be the starting point to give a wider understanding of the site and its potential features and anomalies. These can then be more specifically targeted with further survey types. With more time and development EM surveys could also be used for these wider site surveys, rather than just for the investigation of of specific targets. Earth Resistivity Tomography and Induced Polarisation should then be used to investigate the vertical extent of deposits and features. However, due to the time and potential cost of these survey types they should only be undertaken with specific aims in mind, until such a time as the technique becomes more mainstream and accessible.

For the investigation of iron production sites these geo-prospection techniques have shown the ability to map the positioning of features an anomalies through the horizontal axis, magnetometry and EM, as well as gaining an interpretation of depth and form of the deposit or feature, Earth Resistivity Tomography and in some sense EM, as well as giving a more in-depth interpretation of the material forming the features and anomalies, Induced Polarisation and EM. All of which lead to a more in-depth interpretation of the site allowing for more rigorous planning for further investigation.

Excavation and Analysis

As has been discussed the approach taken in this project to excavate in spits rather than stratigraphically, although not the standard approach, has been seen to be the most appropriate technique for excavating through technological waste deposits on iron production sites in order to collect material for quantitative analysis of the technological waste. This allows for the ability to collect samples in a standardised process, with an amount of flexibility in collection, while still giving the ability to inform on stratigraphy.

The amount of material collected and analysed in this project was a decision made as a trade off between data gained and time available. It is believed that this project has shown that the amount of material collected for analysis was an adequate amount to answer the aims of this project. With more time a larger percentage of the small and matrix inclusions could be analysed for additional information. However, it can be concluded that the amount of material collected in this project for analysis is the least amount, and any less may lead to loss of information and therefore a miss-interpretation.

The transformation of weight data into %wt of the spit has shown to be a good way to normalise to data and statistically remove any errors in volume of the spits excavated. This also becomes an easily calculated standardised unit which can be applied to all future projects to allow comparison, even if different spit sizes are used.

The non-bias approach to forming the types within this project has been shown to work in identifying a number of different types. This process still needs some development throughout further projects, but it has been shown that by collecting complete data information can be transferred and grouped to match types from other classification systems.

As this project is looking at the organisation of iron production throughout the landscape and not in-depth on a specific site only the 'standard' types were compared statistically. This has been shown to give information on the smelting processes on the site including technology being used, working practices, and possible intensity of smelting. However, with all samples being analyses the raw data can be reanalysed to look more specifically at individual sites.

The intensity factor calculated by comparing the ratio of furnace material to slag and turning this into a percentage allows an understanding of the possible rate of waste production, and therefore smelting production, in comparison to burnt clay and furnace material production which is believed to represent repair or rebuild of the furnace. This intensity factor can then be used on a site basis to understand how the intensity of smelting change over time or between sites to understand the smelting intensity across the landscape. In this project this has been clearly shown between a large industrial scale site and a smaller itinerant site. This theory deserves further development in the future.

Other aspects of identification in the classification system have shown the ability for a number of other interpretations of the smelting processes on the site and possibly across the landscape. One example discussed were the large amounts of iron ore embedded in the base of the slag at Chitcombe and the glassy material at Standen.

It has therefore been seen that through the analysis and classification of technological waste from iron production a number of aims have been met with information gained on the social organisation of Roman iron production across the Weald on an inter and intra site level. It has also been shown a level of understanding of smelting processes can be understood and interpreted thorough the classification and analysis of technological waste

10 Interpretation of iron production in the landscape

10.1 Introduction

In this chapter all the data collected and analysed throughout this project will be synthesised and interpreted. Both Chitcombe and Standen will be interpreted separately and then compared in light of the geo-prospection, material weights, and analysis data collected by the project. These sites will then be discussed in terms of their position within the wider landscape of iron production in the Weald and assessed in terms of the new data that has been added to the understanding of the social organisation and control of production.

10.2 Wider interpretation of the sites

Both sites will be interpreted and discussed looking at their scale of production, iron production features, dating evidence, wider site features, and processes, organisation, and control of the sites.

10.2.1 Chitcombe

Scale of production

As a site Chitcombe has been identified as a large scale through survey work and excavation (chap 4 and 5). Its technological waste deposit extends for a few hundred metres and has a depth at certain points of 2m. This varies and could increase nearer to the ghyll-side but is also shallower in places. All technological waste is not consistently deposited within the waste heap but also utilised across the site for such things as track making.

Chitcombe, due to certain features within the site, can be treated as an industrial site. The term industrial is used here in a specific way with a definition that states that a product is made from raw material within a factory in a repeating process. This industrial interpretation is given to Chitcombe because it has smelting workshops, identified across the site which consist of four interpreted furnaces within an enclosure setting (fig A.36 and A.37).

The scale of production at Chitcombe could also be informed by the intensity of smelting occurring on the site. As was seen in Chapter 5 Chitcombe was shown to have a high smelting intensity where there is a higher ratio of slag to furnace material implying a larger number of smelts to furnace repair or rebuild. This could been seen to show an increased scale in production, not in terms of volume over time but volume in production between repairs and rebuilds.

Metallurgical features

There are a number of features across the site that can be specifically attributed to processes relating to metallurgy. These include furnaces, the technological waste, and workshops.

FIGURE 10.1: Chitcombe trench 18 - remains of furnace structure

At Chitcombe the furnaces (fig.10.1) within these workshops are potentially up to 1.3m in internal diameter meaning a substantial amount of iron could be produced per smelt and would have needed a considerable input of time and resources to run a single furnace. If multiple furnaces were in use simultaneously this would increase resource organisation. At Chitcombe there is a potential to have 8 furnaces running. There also seems to be a large degree of planning and construction put into the furnaces placing them in a setting edged with very large stones and layers of burnt clay built up inside where another layer of stones was used to create the furnace setting (trench 18 fig 10.1, ap B.2). It is difficult to interpret why such a large surrounding structure was constructed for the furnace as there is very little structure left, but a possible interpretation would be for insulation of the furnace to help with heat loss and make the process more efficient or a large built up surround could allow for easy access to the top of the furnace for introducing raw material. Also, a well-constructed, solid setting would give the furnace durability, especially if it was being used intensely. It could be argued that over time the rebuilding of the furnace moved it forward and the surrounding structure extended with it. However, this is not believed to be the case due to the large inner stone clearly marking the furnace area, and if there were rebuilds over a long period it could be expected that such large settings would be embedded further back in the structure. Such large furnaces (fig.10.2) can be compared to those discovered at Laxton, Northamptonshire (Jackson et al., 1988).

From surveys and excavation, it has been seen that there are a number of possible structures that are connected, but outside, the smelting workshops. These structures are rectilinear in their form, according to the magnetometer survey (fig A.36), and in one a large amount of roasted iron ore was discovered during excavation which may show these as storage spaces for material or even areas for processing and preparing raw materials for the smelting process.

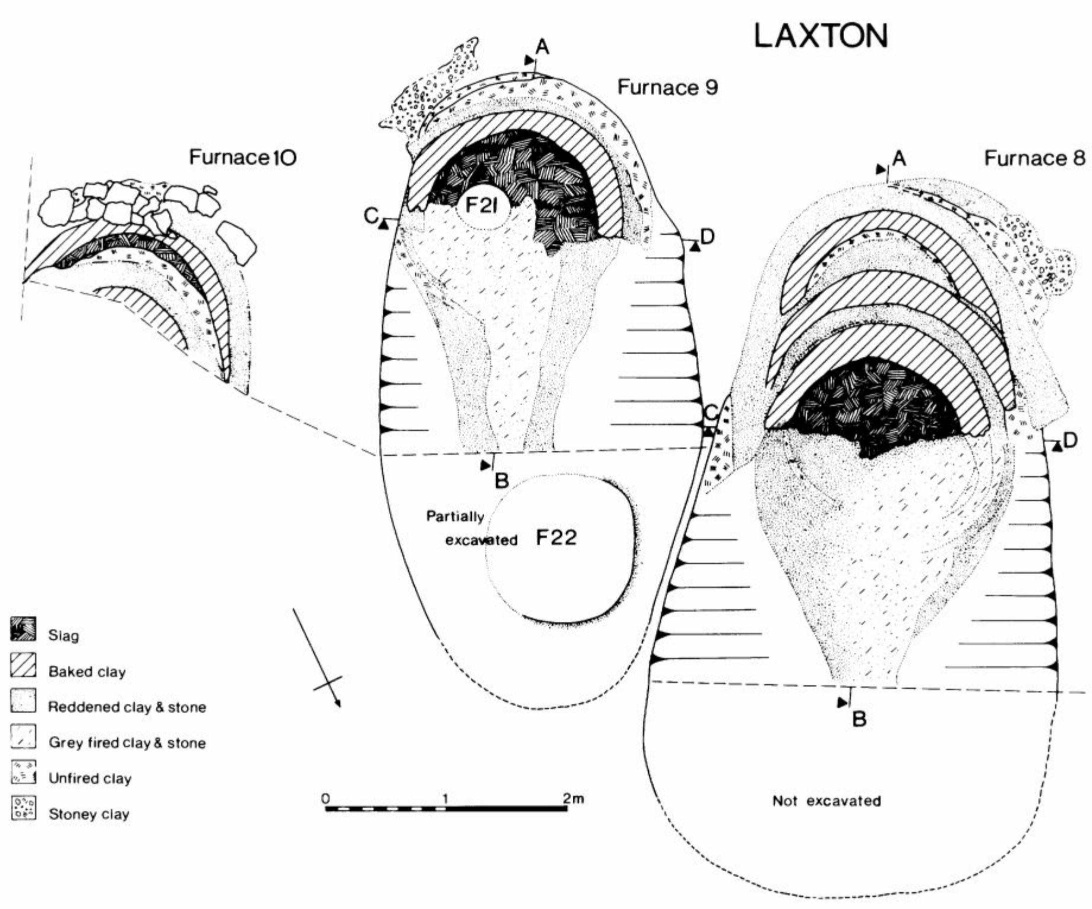


FIGURE 10.2: Drawing of furnaces from Laxton

Dating evidence

According to analysis of the pottery by Malcolm Lyne there were 734 sherds discovered on the site of which 322 were from stratified contexts (Lyne, 2017). The majority of the pottery identified dates to the 1st and 2nd centuries, with a few sherds datable to the 2nd to early 3rd centuries AD.

When looking at specific deposits of pottery, it can be seen that trenches associated with the smelting workshop have early dates of mid-1st to late 1st or very early 2nd century.

The pottery from the quantitative trench (trench 14) excavated into the technological waste deposit also shows early dates with a total range of AD 43 to AD 150 (fig.10.3). This correlates with the date range of the smelting workshop. As trench 14 was associated with the eastern smelting workshop this could imply that both were functioning at the same time.

FIGURE 10.3: Pottery from Chitcombe

Wider site features

Across the full site there are a number of features which give a wider context and interpretation to the site.

The first of these is the ditch which demarcates the smelting workshop which could have a number of purposes. The first could be social, marking out the smelting area as a workshop and giving it its place within the site. It could also be practical, with the Wealden clay prone to waterlogging, the ditch could be used as a drainage system to keep the smelting area dry, allowing for a more efficient and controllable smelting. Without further investigation of these features their interpretation of their use cannot be said for certain.

Another major set of features at Chitcombe is the remains of a stone and tile building with associated beam-slot which was identified in the northeastern corner of field 2 in trench 3 (ap B.2, fig 5.21).

The evidence of these structures, interpreted as a bathhouse with associated wooden buildings near by, shows a high level of Romanisation and investment of resources into the site. In this early period, according to the pottery dates from the site, this would only be done by the elite Romans entering into Britain with the invasion and, with the discovery of a military bead used for adorning horses (fig.10.4a), this could be a unit of the Roman military. Moreover, box-flue and a strigil (fig.10.4b) (Cornwell and Cornwell, 2017) are artefacts that have been discovered that would be expected with the construction and use of a bath house. There are a number of possible comparisons with this which will be discussed later.

All across the site there are a number of track-ways which enter and exit the site in all directions (fig A.36 and A.37). This shows that Chitcombe was not just an individual iron production site but was a hub in the centre of a wider landscape.

(A) Military bead, Chitcombe

(B) Strigil, Chitcombe

FIGURE 10.4

Processes, organisation, and control

A specific process identified at Chitcombe is the use of iron ore fines within the base of the furnace. This has been observed in experimental iron smelts with charcoal fines or ash, and no mention can be found in the literature as to other examples from within the Weald to this kind of practice. One furnace was excavated to the extent of understanding its fill on this site (trench 18), but the evidence from the technological waste deposit could imply that this practice was used across the site.

There was no clear evidence of defined bloom smithing areas discovered on this site. However, this does not mean it was not present. There are many areas of high magnetism which could be areas of smithing but without further investigation no confident interpretations can be made. In the matrix inclusions category a number of spheroidal slags were identified which are formed during smithing, mainly the bloom consolidation phase, by the expulsion of the slag from the iron upon hammering. However, these were not identified in sufficient abundance, as would be expected. This shows a certain level of smithing must have occurred but without more investigation it cannot be said if this is just bloom consolidation, or bar smithing and product smithing as well.

As was seen in the technological waste deposit at Chitcombe there is apparent evidence, through the analysis of material and looking at the excavated contexts, of a cyclical process where there is an intense period of smelting that produced a large amount of slag with subsequent cleaning out of the furnaces and repair or rebuilding work (section 5.4.2). This has been a long standing belief in the discussions surrounding iron production, with one of the first discussions and representations given by Rock (1879) using an image of an etching made showing repeated bands within the technological waste deposit at Beauport Park (fig.10.5).

This idea deserves some discussion at this point to understand if this observation is valid.

The act of depositing waste material, be it slag or furnace material, is going to occur at a discrete point in space and time. In this sense it can be understood that material from specific processes is going to form distinct deposits within a larger waste deposit. This suggests complete intermixing is unlikely and in a large waste deposit, such as seen at Chitcombe, there is a low probability that material from different furnaces would be deposited in the same spot in space and time. This act of unique deposition would then result in obvious contexts of different material deposition leading to the interpretation of a cyclical process.

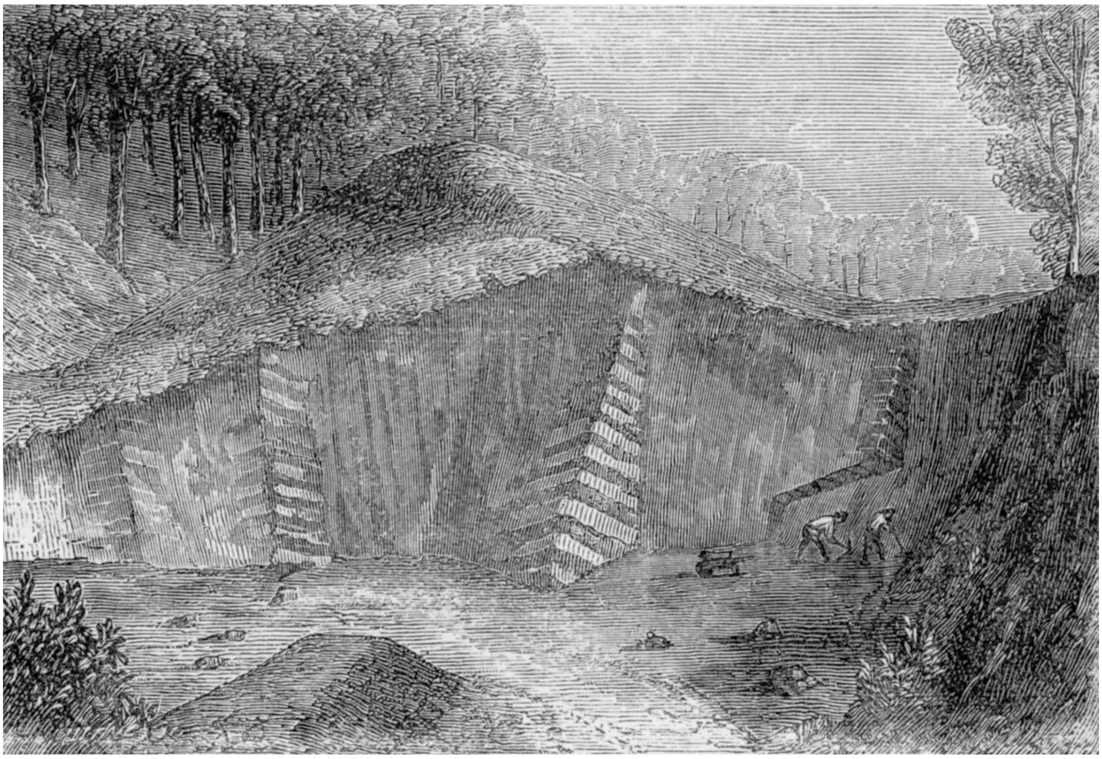


FIGURE 10.5: Engraving of TWD at Beauport Park

If only a single furnace was in operation on a site it would logically stand that smelting and repair or rebuild of the furnace could not occur at the same time, furthering the unique depositing of specific materials. On a site such as Chitcombe which has at least eight furnaces these two processes could occur at the same time. However, as discussed, it does not follow that the material would be discarded in the same place. This then brings the interpretation of time as part of the interpretation of a cyclical process. With the ability for materials to be discarded at any point in the waste deposit it does not stand that deposits directly above or below each other are connected by linear time but are as likely to be out of time. Therefore, interpreting a cyclical process across a site by looking at repeated stratigraphy could be seen as simplistic.

The stark differences in the contexts within a waste heap to identify a cyclical process could be more of an indicator of speed of deposition and intensity of smelting, as has been previously discussed in Chapter 5 and 7.

The clear demarcation of processes on this site show a level of compartmentalisation and organisation, but maintains the generally agreed layout of an iron production site (Hodgkinson, 2008). Heading away from the stream or river, is first the waste deposit, then the area for smelting, and then other process, which at Chitcombe are workshops or storage areas. There is a possible area of habitation to the south of the trackway, further away still from the river and the smelting area, but this is unclear and unconfirmed.

Chitcombe, in the light of everything discussed, can be seen as a large scale industrial site, probably, under the organisation and control of a section of the Roman military or establishment. It is however unclear as to the exact nature of who is in control.

There have been no discoveries on the site which point to the direct involvement of the Classis Britannica. However, caution should be taken as there is evidence for robbing of material from the site as seen in the very minimal remains of the proposed bath house, and what looks to be chip marks on the edge of the tile. This could indicate that material has been removed from the site and therefore cannot be identified. Moreover, the site is very large and the main areas of habitation have yet to be discovered. Moreover, tiles from the CLBR do not tend to appear until after AD c.120 (Cornwell and Cornwell, 2017) which post-dates this site. Therefore, until specific evidence is found or an accurate comparison can be made the only interpretation that can be made is of Roman military control.

10.2.2 Standen

Scale of production

Standen can be treated as a small scale site as seen through survey work and excavation (chap 6 and 7). Its technological waste deposit extends for 50m along and down the ghyll-side and up to 1.2m deep according to excavation. The intensity of smelting is low as demonstrated in chapter 7 from the intensity factor, ratio of slag to furnace material, and how the formation of the waste deposit lacks any definition of contexts.

Metallurgical features

There are two main groups of features on this site. The technological waste deposit, and iron production furnaces. Due to time and physical constraints on the site the furnaces were not investigated to their fullest extent. Therefore, their size and form cannot be commented on. The technological waste deposit can assumed to be mostly intact unless material has been moved long distances for road building. The only movement of the technological waste deposit would be via farming practices which would increase the apparent size of the deposit.

Dating evidence

It is very difficult to precisely date this site, beyond placing it in the Roman period, and state how long it was in use for to the lack of stratified pottery or other dating evidence. None of the pottery used for dating evidence discovered in this project is stratified and has a combined date range covering from the late Iron Age to the early 3rd century AD. The pottery that was discovered in the original investigation of the site by Straker and Mason (1939) does not have a clear context, and at the time of assessment was placed as 'Roman with a strong native influence' with a possible 2^{nd} century AD date being given to a single piece of Samian ware. It therefore cannot be said for certain if this site was established and in operation over a few years or many decades.

Wider site features

Due to the time limits of this project surveys did not progress far beyond the primary iron production area. However, with previous research carried out on the site it is not believed that there are any further associated features or structures in the near vicinity that are connected to the iron production site.

Processes, organisation and control

It can be seen that there is a specific process occurring on this site which produces as a waste material a highly silicious 'glassy' slag (fig.10.6). The reason for this material is likely due to high reducing condition and temperature in the furnace.

Looking at the contexts in the waste heap it was not possible to identify clear evidence of the life cycle of the furnace with alternating large deposits of furnace material indicating rebuild (fig 7.6). However, with the analysis of the technological waste it could be seen that the representation of waste was not

FIGURE 10.6: Glassy slag from Standen

constant and therefore shows periods where more furnace material was entering the waste deposit possibly representing times of repair or rebuild. However, the data has to be looked at with care.

The only possible organisation on this site is the possibility that the furnaces are positioned on flat ground at the top of the ghyll-side next to a working area that is most likely formed of technological waste and debris. All the rest of the technological waste is then deposited down the ghyll-side. This is the expected organisation of a iron production site and has been seen widely across the Weald (Hodgkinson, 2008).

There is no evidence on the site as to who was producing iron or if there was any form of formal control over the site.

10.2.3 Comparison of sites

Looking at all the information and data presented it can be seen that Chitcombe and Standen are vastly different sites.

Scale of production

The scale of both these sites are at opposing ends of production in the Weald with Chitcombe representing a large scale industrial site and Standen representing a small scale non-industrial site.

Metallurgical features

As would be expected, both sites have evidence of furnaces for smelting iron and technological waste deposits. It is not possible to compare the furnaces on these two sites as they were not part of the investigation at Standen.

There is no evidence of areas for preparing the materials necessary for smelting at Standen. This does not mean they are not present as they could be slightly off site, closer to the sources of the materials or not clearly demarcated as at Chitcombe.

Dating evidence

The majority of the pottery used for dating evidence at Chitcombe came from features associated but not directly linked to smelting such as ditches. With no features like these present at Standen available for investigation it removes major sources of evidence.

The fact that more pottery was discovered in the technological waste heap at Chitcombe could be attributed to two reasons. The first is luck, with such large deposits the trench at Chitcombe may have been placed in an area where pottery was deposited whereas at Standen the trenches were not. The second is that there is more pottery at Chitcombe than Standen. It would logically follow that there would be more pottery present at Chitcombe because of the difference in scale of the site. It must be concluded that there were considerably more people at Chitcombe than Standen bringing more pottery to the site. It could also be theorised that at Chitcombe there are possible links to habitation on the site which would mean that all personal belongings and pottery used for everyday living would be present on the site and the logical place to discard breakages would be on the technological waste deposit. At Standen there is no evidence of settlement. Therefore, if the workers are travelling to the site, even as small a distance as a mile, then generally pottery for living would not be present on the site. Also, the presence of pottery suggests higher economic status.

Wider site features

There are no wider site features to compare. This may be due to the extent of survey work at Standen not being as wide ranging, or on these small scale sites they are specific smelting areas with no other features nearby. This could be evidence by the fact there was no indication of track-ways at Standen, showing there was not enough movement in and out of the site to warrant their building creation, again indicating lower economic status.

Processes, organisation, and control

Both Chitcombe and Standen are utilising a slag tapping processes in their furnaces for smelting through the evidence of fluid movement tap-slag. Unlike Chitcombe, Standen has a high representation of glassy and light porous slag. This could show a difference in the physical smelting process on site including 'ingredients' and ratios of materials for smelting and conditions within the furnace. The evidence of ore fines on the base of the slag from Chitcombe is not present at Standen. It can be interpreted with confidence that the practice of packing the base of the furnace with ore fines is not occurring at Standen.

The organisation of these sites are similar in the sense that both their technological waste deposits are positioned down and along ghyll-sides with the furnaces positioned on the flat ground above. Chitcombe then has more features positioned beyond and around the main smelting area.

This positioning is interesting as it could show an effect of human nature in the positioning of structures for efficiency or an established custom in setting up an area for producing iron.

10.3 Iron production through the landscape

With both these sites now fully discussed they need to be understood in their wider landscape setting, to see if with the new information gained from this project, previous knowledge and understanding of the landscape of Roman iron production in the Weald needs to be reassessed.

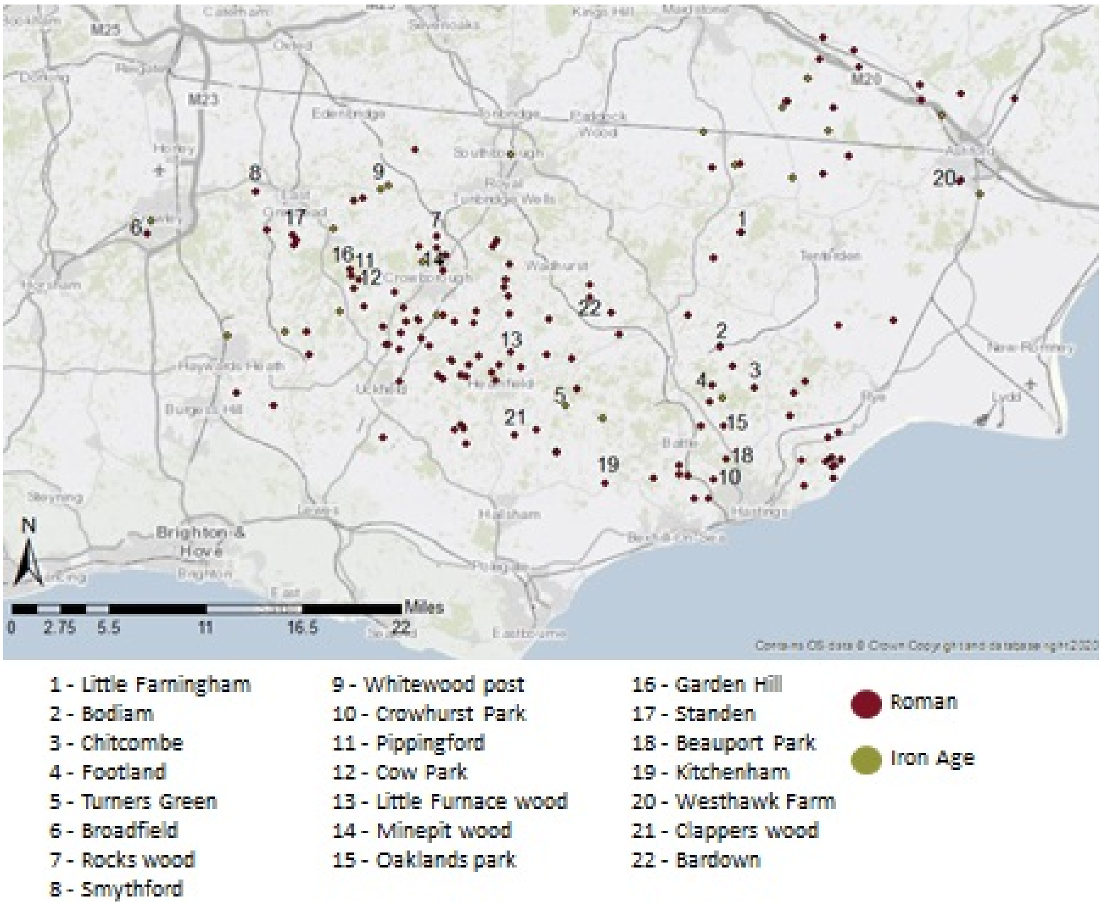


FIGURE 10.7: Position of sites being discussed

10.3.1 Wider investigation of Roman iron production sites in the Weald

There have been many investigations into iron production sites, from field walking and forays, to small scale investigation and large site development-led investigation. A small number of these investigations will be set out here to give a general overview of the Weald including sites that will feed into larger discussions. All sites being discussed are plotted in figure 10.7. However, this list is not exhaustive and if more sites and information is wanted the WIRG website has a more comprehensive database (WIRG, 2019).

Little Farningham Farm (Aldridge, 2001) is an iron production site positioned to the north of the Weald. It has been dated from pottery discovered in excavations to between the 1^{st} and second century AD. This site is positioned on a Roman road heading north out of the Weald from the centre of the High Weald, through the port of Bodium to Little Farningham farm and beyond. This site contains a number of stone structures as well as a large number of post-holes across the site (fig.10.8). There is also evidence of CL:BR tiles, implying the presence of the Classis Britannica. This site contains a considerable amount of evidence of iron production including tuyeres and a bellows pot, as well as large amounts of technological waste and evidence of furnaces (Aldridge, 2001). The excavations on this site occurred in the 1950's with another two trenches being excavated in the year 2000. All the excavations were focused on understanding the buildings and Roman road, therefore the organisation of the iron production portion of the site is not clear. However, with the apparent date range of the site and evidence of Roman control through the CL:BR, this site has many similarities with Chitcombe and Footland Farm. The true organisation of this site could be understood with a multi-geo-prospection survey project.

Turners Green (Beswick, 2003) is an iron production site situated in the south-west of the High Weald. From carbon dates obtained from with the furnaces discovered during excavations in 1970-1971 as well as pottery, the site has been dated to the 1^{st} to 2^{nd} century AD. The site consists of a main iron production area with a number of outlying furnace sites as well as an ore roasting area.

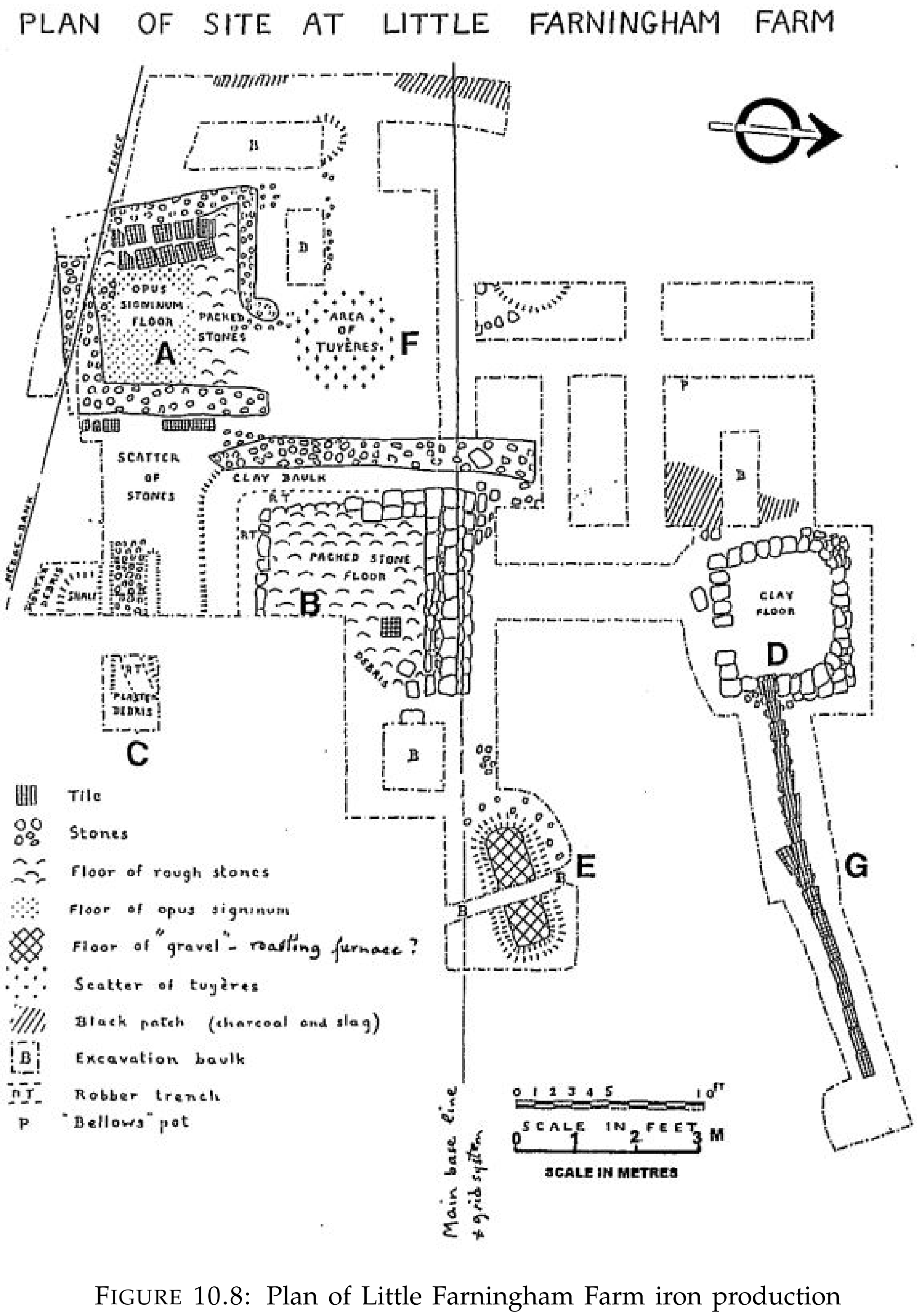


FIGURE 10.8: Plan of Little Farningham Farm iron production site

The main iron production area on this site is positioned at the bottom of a small ghyll. Along one edge of this small ghyll are five furnaces. Of these furnaces four are constructed abutting each other and one is positioned on its own to the west (fig.10.9). Along the opposite bank is a stone-built platform with abundant evidence of smithing. This is one of the most complex preserved iron production sites identified in the Weald. With the four furnaces positioned in a line and the date range of 1st century into 2nd this site has a number of identifiers that could indicate this site is covered by Roman military control. Although a magnetometer survey was conducted on the site which helped delineate the extent of the site and identify the outlying furnaces, this was completed in the 1970s when magnetometer surveys in archaeology were in their infancy. Therefore an updated multi-geo-prospection survey should be conducted on the site to understand its full extent.

Broadfield (Cartwright, 1992) is a large mixed site covering around 12 hectares in the northwest of the High Weald uncovered during large scale construction work. Broadfield consists of a number of domestic and iron production areas with an extensive occupation ranging from the 1^{st} century BC through to the 4^{th} century AD, with the height of occupation and production between the 1^{st} and 2^{nd} centuries AD. These dates were obtained through carbon dating and pottery discovered during excavations. The iron production at Broadfields consisted of over 40 possible iron production furnaces and three technological waste deposit. However, there was evidence of a large amount of robbing and reuse of the technological waste meaning these technological waste deposits were no longer their true size when excavated, and have since be largely built

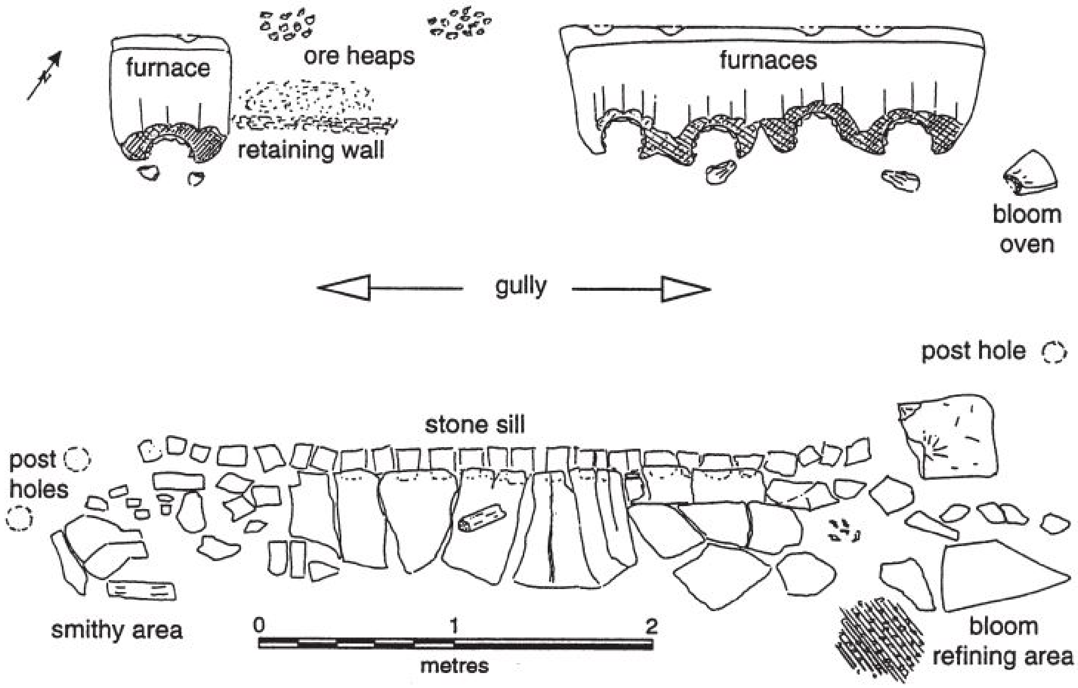


FIGURE 10.9: Plan of furnaces at Turners green iron production site

over. There was also evidence of a number of ore preparation areas and a smithing workshop. Throughout this site there was no evidence of Roman military or CL:BR control. When this is looked at in conjunction with evidence of continued use from late Iron Age through to the later end of the Roman occupation of Britain this site could be interpreted as being occupied by local non-military people with a continuity from pre-Claudian invasion.

Rocks Wood (Harding and Ostoja-Zagorski, 1987) was a small iron production site positioned in the mid-west of the High Weald and consisted of a single furnace positioned within a rock shelter. Sherds of local East Sussex ware discovered on the site gave a date from late Iron Age to early Roman. The furnace measured 0.7m wide by 1m long and was formed of clay and stone and evidence of tap slag showed the technology being used. This site showed the possible variety of iron production sites present throughout the Weald.

Smythford (Hodgkinson, 1985) was a small iron production site positioned to the north west of the High Weald. This site consists of three locations along the Felbridge Water, two of which have been investigated. One of these locations was a waste heap that contained technological debris with no regular pattern or stratification. In the second area two structures were discovered, one was interpreted as reheating hearth and the second an iron smelting furnace. There were also large areas of charcoal and roasted ore staining.

Whitepost Wood (Stevens, 2013) was a small iron production site to the north of the High Weald. The site was identified by WIRG during a foray and dated charcoal recovered from the site placed it in the later Anglo-Saxon period. Upon excavation the site showed a spread of technological debris with inclusions of pottery but no in situ furnace. The pottery from this deposit has been shown to be mid- to late-Iron Age. This shows the issues with dating iron production sites just by investigating the technological deposit.

Crowhurst Park (Straker and Lucas, 1938) is an iron production site to the southeast of the High Weald. The site was excavated in 1936 when a modern pipe was placed through the site. The extent of investigation into the site records that there was the expected technological waste from iron production including slag, furnace material, ore and charcoal. There was also evidence of single and double tuyeres. Pottery from the site placed it in the 1st and 2^{nd} century AD. The extent of the waste deposit remains on this site is large to this day, with evidence of substantial removal of material in more modern times showing this could have been an exceptionally large site. Crowhurst Park sits within the vicinity of other large sites such as Beauport Park, Footland Farm and Chitcombe. This site is one that could do with re-investigating with modern equipment to truly understand the organisation of this site beyond the technological waste deposit.

Pippingford (Tebbutt and Cleere, 1973) is an iron production site in the west of the High Weald. The site was excavated in the early 1970's and slag was identified on a platform cut into a ghyll-side. This platform had been reused in more modern times for charcoal production, however there was still the remains of a single furnace and smithing hearth along with a number of post-holes showing the possibility of structures around the furnace. The furnace discovered had an internal diameter of around 60cm with the walls being formed of sandstone blocks and clay to a thickness of around 40cm. At the front of the furnace was a depression measuring 80cm wide by 1m long and 35cm deep lined with stone. Where this depression met the furnace was a slightly deeper hole lined with ash and charcoal which entered the furnace through a small arch. This showed how the slag would have been tapped out of the furnace into a small depression. This site was dated by finds of pottery to the 1st century AD. The thickness of the furnace wall to its internal diameter shows a construction process similar to that at Chitcombe. This could therefore be a common construction practice.

Hartfield - Cow Park (Tebbutt, 1979) was an iron production site in the west of the High Weald. The site was excavated in the late 1970's having been previously identified as a possible site and believed to be a good option for excavation due to its open nature. During excavations a working floor was identified with its full extent completely exposed. Within this working area were identified three furnaces with associated reheating hearths and a smithing area. Two of the furnaces were smaller and very similar in form, the third was larger and contained a thick layer of charcoal fines in its base. In the smithing area a feature was identified which was believed to be the remains of an anvil being constructed of wooden stakes supported by clay and topped with an iron plate. The wider area did not show any other major identifiable features. A number of post-holes were identified throughout the site but none formed the coherent outline of a structure. This site was dated with pottery found in excavations to the 1^{st} and 2^{nd} century AD.

Little Furnace Wood (Butler, 2020) was an iron production site situated in the centre of the High Weald. The site was excavated between 2003 and 2007. The initial aim of the excavation was to obtain dating evidence from the technological waste deposit. However, upon excavating the deposit the remains of a furnace were discovered. The excavation was then extended leading to the discovery of two furnaces and an ore roasting pit. One of these furnaces discovered was around 1m in internal diameter and over 1m tall which is a rare level of survival in the Weald. A number of post-holes were identified around the furnace which could indicate a structure such as a wind break or shelter. A large ore roasting area was discovered some distance from the main area containing the furnaces. This site has been dated from the 1^{st} to the 4^{th} century

AD through archaeomagnetism, carbon dates and pottery finds. Carbon dates from the furnaces place them more towards the earlier dates in this range.

Minepit Wood (Money, 1974) was an iron production site positioned in the mid-west of the High Weald. The furnace identified during these excavations had an internal diameter of 0.6m with vertical preservation of up to 0.6m. At the front of the furnace was a large depression measuring around 1.8m long and lined with sandstone blocks. Three blowholes were identified in the structure of this furnace at right angles to each other with reference to the front of the furnace. The waste deposit was investigated at Minepit Wood to understand stratigraphy and to identify the material it was formed of. Money described the materials in a very general way naming tap slag and cinders as well as furnace lining and charcoal. There is also mention of evidence of glassy material attributed to accidental charging of shelly limestone. The wider smelting area was also excavated leading to the identification of a possible structure containing a hearth which has been interpreted as a form of shelter for the workers. Through pottery and carbon dates this site has been shown to have a long period of occupation ranging from the 1^{st} century BC to the 5^{th} century AD.

Oaklands Park (Staveley, 2015) is an iron production site positioned in the southeast of the High Weald. This site was surveyed and excavated in 2013 by the Independent Historic Research Group as well as extra survey work and interpretation completed by Greenwood (2014) as part of an undergraduate dissertation. A number of features across the site were investigated with different geo-prospection techniques including magnetometry, resistivity, ground penetrating radar, and EM. This identified a number of different features on the site including the possible extent of the waste deposit, ditches and track-ways, a rectangular building, and possible furnaces. A number of trenches were excavated across the site to try and identify if the site was under the control of the CL:BR. None of the features pertaining to iron production were investigated. Although this is one of the largest iron production sites in the Weald there is no clear evidence on this site of the smelting workshop. This site has a large date range with pottery dating the site from the 1^{st} to the 5^{th} century AD. Pottery from the late Roman and early Saxon periods were discovered in the foundation trench of the building on the site.

Garden Hill (Money, 1977) is a multi-phase site positioned in the midwest of the High Weald. This site started as an Iron Age hill fort before becoming a Roman site. The evidence for iron production on this site is within the Iron Age hillfort and dates to the 1^{st} century AD. This includes furnaces, hearths, ore roasting areas, and a waste deposit behind the ramparts to the hill fort. There is evidence that all of these were demolished to make way for later building. There are a number of rectangular timber buildings dating to the 1st century which could be associated with the iron production. By the time the iron production has stopped in the 2^{nd} century AD a small bath-house was constructed on the site (fig.10.10).

This shows that Chitcombe and Standen sit in a landscape of iron production sites that contain a broad range of form, features, size and date-ranges. Chitcombe sits on the upper end of the scale when it come to quantity of material. However, its smelting workshop more closely matches the organisation

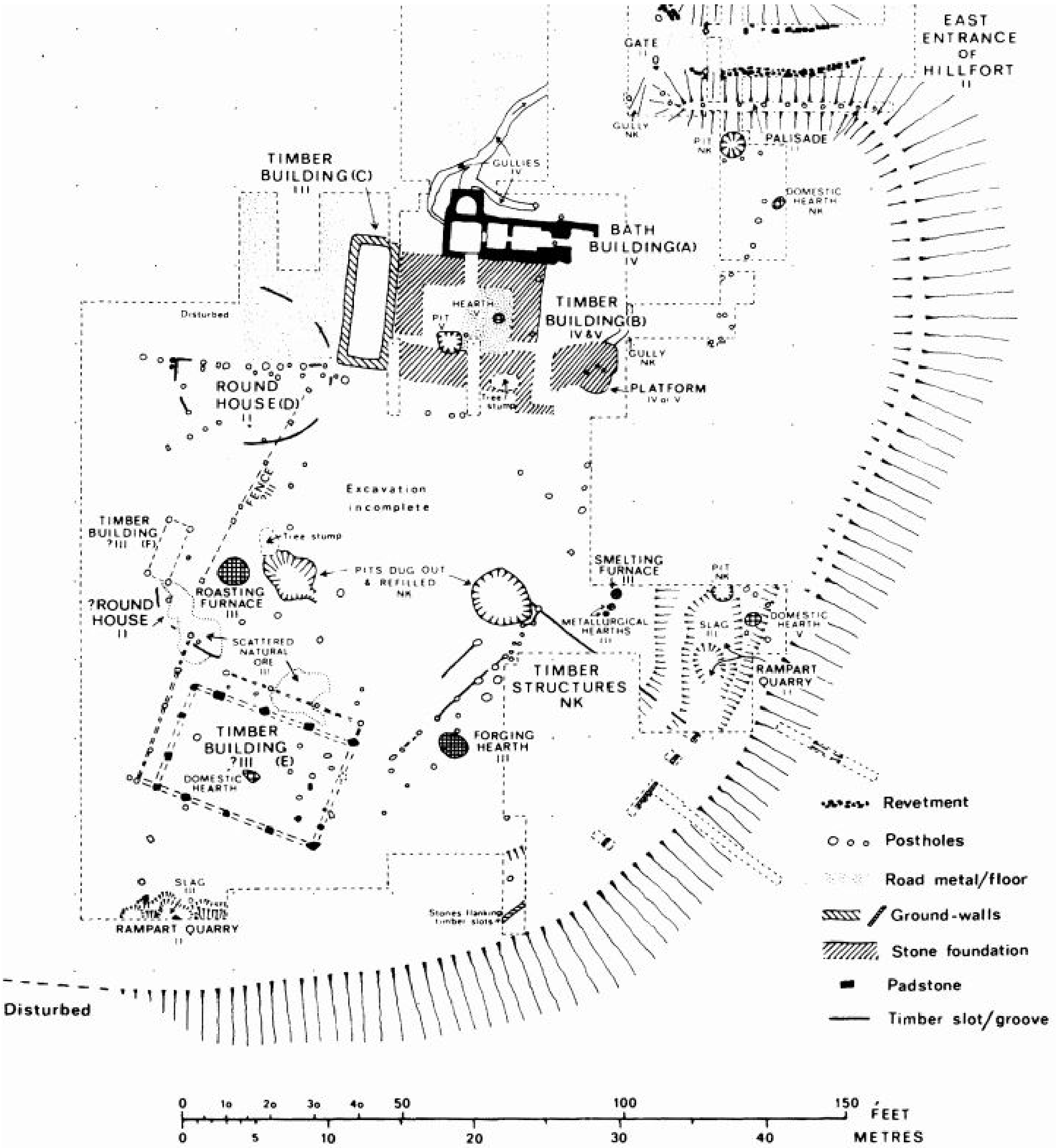


FIGURE 10.10: Plan of Garden Hill with iron production site and bath house

of Turners Green, a smaller site, than Oakland Park, a large site. Standen is at the lower end of the scale of size with no clear interpretation.

10.3.2 Landscape of Roman iron production in the Weald

Scale of production

The scale of iron production sites throughout the Weald varies greatly in terms of the size technological waste deposits and features across the sites.

The size of the technological waste deposit on a site is fraught with difficulties when trying to calculate. In terms of lateral extent many modern day processes, mainly farming practices such as ploughing, have caused the spread of material. Moreover, it is clear that technological waste was used across sites for a number of functions such as track building and possible floor gravelling. Therefore using techniques such as metal detectors, magnetic susceptibility meters or probing to feel the material will often give a misleading results. Even, magnetometry surveys should be used with caution for this purpose.

As with the issue calculating the horizontal extent of the technological waste deposit, there are also issues with calculating the depth of the TWD. Earth Resistivity Tomography and Induced Polarisation has been shown to be useful in the estimation of the depth of the deposit but more work is needed in making this more accurate. However, the time and resources that would be needed for this is extreme and questions would need to be asked as to whether the outcome warrants the investment.

The classification of industrial sites as identified and described within this project has shown that 'industrial' does not necessarily mean big and vice versa. Examples of this are Kitchenham Farm and Oaklands Park. Oaklands Park is a large scale site in terms of the perceived volume of its waste, however the smelting workshop identifying the site as industrial has not been recognised and therefore cannot be called industrial. On the other hand Kitchenham Farm is small scale site in terms of the apparent volume of its waste, however this site does contain evidence of a smelting workshop and can therefore be classed as a small scale industrial site.

Metallurgical features

The two main metallurgical features identified on these sites are the furnaces and the technological waste deposits.

It has been shown through this project that investigation of the technological waste deposits can give a lot of information in many aspects of the smelting process occurring on the site, whereas investigation of furnaces only gives information of the form of the feature and the technological process. It can then be said that for understanding the main focus when looking at metallurgical sites should be the technological waste deposits. Anomalies believed to be furnaces should still be investigated as there is a possibility of other features such as reheating hearths and ore or charcoal producing features which would then inform on the organisation of the site.

Dating evidence

As has been seen the main way of dating iron production sites throughout the Weald is the identification of associated pottery. In many cases the pottery discovered is local Sussex-ware which has a long date range and means sites can often only be narrowed down to a number of centuries. A number of carbon and archaeomagnetic dates have been used across the Weald which give a more accurate measurement.

Organisation and control

Looking at sites investigated across the Weald it seems to stand that in the majority of cases these sites are positioned at the edge of some form of water, be it river or stream. The technological waste deposit is then positioned on the slope up from the water's edge on slightly higher ground. On this higher ground above the technological waste deposit is then where the furnaces seem to be positioned. Any other features on these sites are positioned away from the smelting area but with no clear pattern. This general site layout is not believed to show a large over-arching organisation but rather could represent an older generalised practical working practice, a representation of the organisation by human nature, or the best places to position features for the most efficient and economical smelt. A caveat must be placed here that recent work in the Weald on a large construction project discovered a Roman iron production site at the top of a hill away from any present day water (Hodgkinson, 2008). This site then moves away from the norm. It is believed this site is not unique and had not been previously identified due to the usual method of identifying sites being to search along stream valleys.

A form of organisation discovered at Chitcombe was the smelting workshop consisting of four furnaces within an enclosure. There is evidence that this organisation of furnaces within a site has been previously discovered on a number of other sites across the landscape of the Weald including Footland Farm

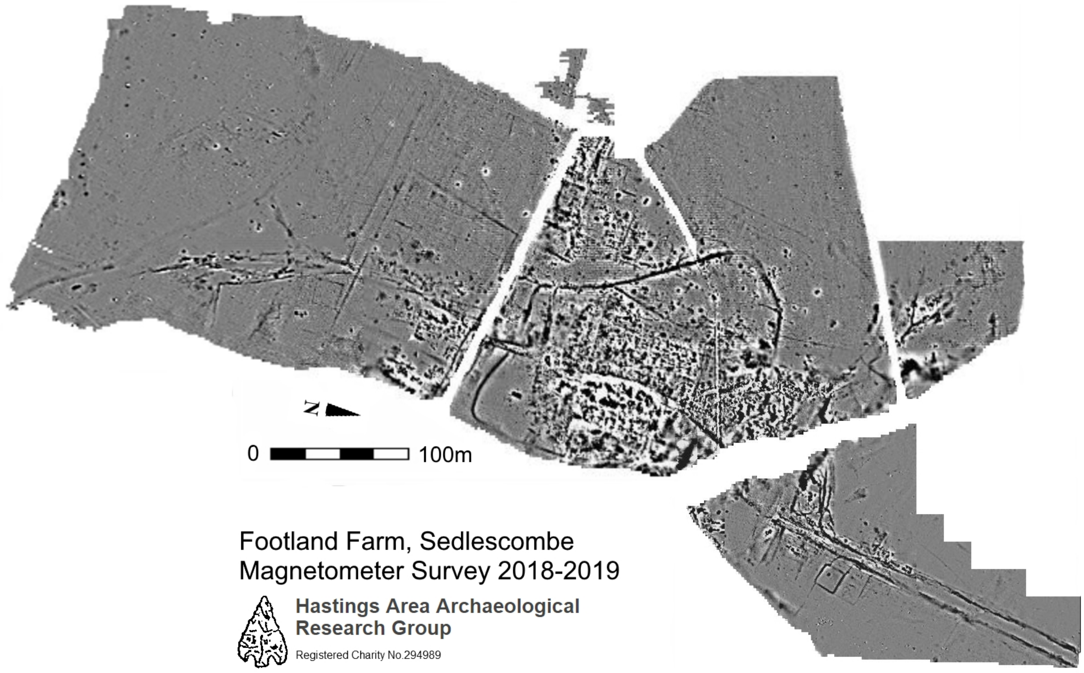


FIGURE 10.11: Magnetometry survey of Footlands iron production site

(fig.10.11) (Cornwell, Cornwell, and Padgham, 2013), Kitchenham Farm (Cornwell and Cornwell, 2007), Westhawk Farm (fig.10.12) (Booth, Bingham, and Lawrence, 2008; Paynter, 2007) and possibly Turners Green (Beswick, 2003). Although it has not been understood in its landscape setting or influence in understanding the organisation of iron production in the Weald during the Roman period until this project. The significance of this organisation on the control of the iron production in the Weald will be discussed later in this section.

The highly siliceous 'glassy' material discovered at Standen has only been noted on one other site in the Weald, Clappers Wood (Paynter, 2006) This material shows a change in the process of smelting on these sites. This change in

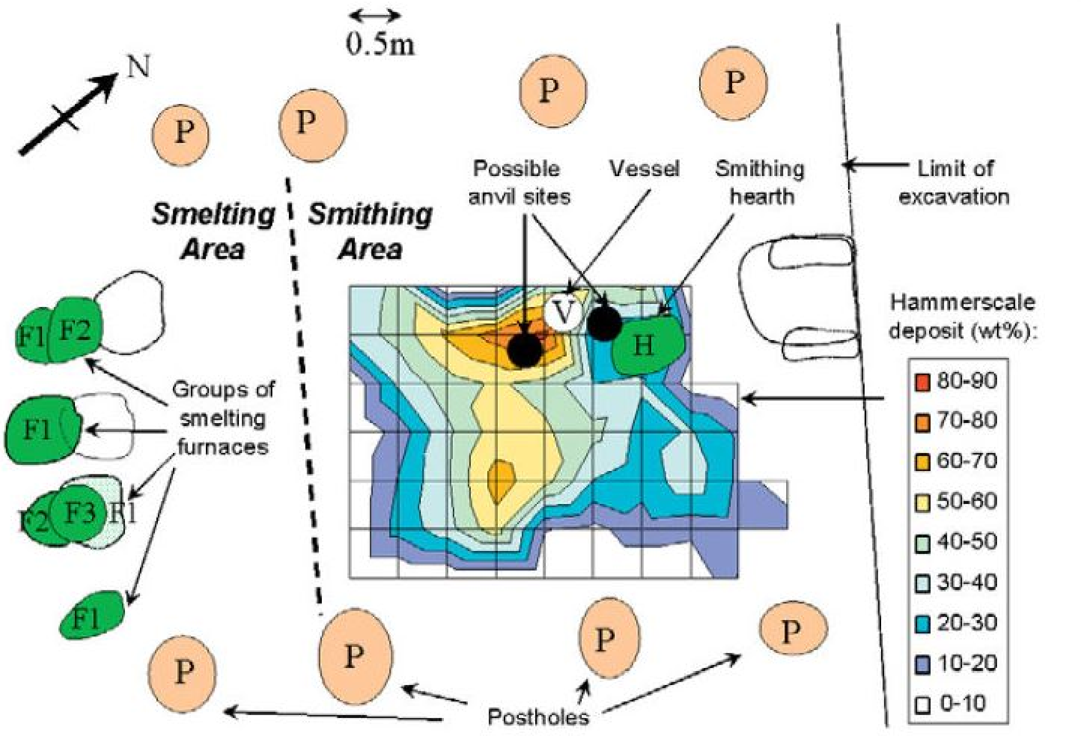


FIGURE 10.12: Furnaces and smithing area Westhawk Farm (Paynter 2007)

process could represent an organisation and dissemination of information pertaining to the technique and processes of smelting, or it could represent two individuals working out how to smelt more efficiently.

There is an ongoing debate within the research of Roman iron production in the Weald as to the level of Roman military or state control of resources, including the theory of an imperial estate (Cleere and Crossley, 1995). In many cases this is settled by the evidence of CL:BR stamped tiles present on the site. Across the Weald there are four sites, associated with iron production, that have CLRB stamped tiles positively identified. These are Bardown, Beauport Park, Kitchenham Farm, and Little Farningham Farm. There are a number of potential issues with this practice of only identifying sites as having a military connection due to the presence of these stamps. One is that a large number of sites have not been investigated and therefore evidence not found. This could then cause a mis-representation of the type of sites controlled by the CL:BR. This is because larger sites such as Bardown, Beauport Park and Little Farningham farm are more likely to be investigated as it is more economical and productive to do so in terms of research and output. The investigation at Kitchenham Farm has shown that these stamped tiles also exist on smaller sites, which could show more extensive representation across the Weald. A second reason is that there is evidence of large scale removal of tiles from sites to be reused elsewhere for such processes as mortar manufacture (Cornwell and Cornwell, 2014b), therefore the evidence of stamped tiles could have been removed from a site. To follow this, if the CLBR are abandoning a site it would seem logical that they would remove material that bore their insignia so it could not be used by anyone else, specifically locals looking for materials. In this sense, stamped tiles may only form a small representation of tiles on a site, particularly on small sites. A third potential issue is with the start date of tiles appearing on sites. These do not start to appear until the early second century, which means that any site being controlled and run by the military before this point may be mis-interpreted. Looking at all these arguments it can be suggested that although the stamped tiles are an indicator of direct Roman control, more indicators need to be identified on iron production sites to give a broader understanding of control.

It is believed that in this project a number of possible indicators of military control have been identified. These include bath houses, on earlier sites, military finds and the newly identified smelting workshops.

The bath houses could be interpreted as an indicator on early sites as these demonstrate a level of societal actions which would be expected among the Roman elites and military. On early sites this then shows a level of control by the Romans, but it could be unclear if this is military, the larger control of the empire, or a high class civilian with other examples at such sites as Beauport Park and Garden Hill. With little evidence of other stone or tile structures across the sites or the wider area of the High Weald, the baths houses are distinctive in their construction material. An example of how this can then be linked to possible military is the first fort at Exeter where the only stone and tile building was the bath house with all other being made of wood.

Military finds, such as the bead discovered at Chitcombe, could be another sign of military involvement and control of a site. Care must be taken as these could be random deposits, but should not be dismissed.

The smelting workshops identified in this project shows an organised working practice, often on a large scale. Dating evidence from Chitcombe and preliminary dates from Footland Farm, show these smelting workshops have a potential date starting at the point of the Claudian invasion in the mid-1st century AD (Cornwell pers comm). With this in mind it could be interpreted that these smelting workshops are being set up as part of the invasion to produce iron for the army moving through Britain. When looking at the positioning of these smelting workshops in the landscape it can be seen that they are not associated with any major settlement. This suggests the iron being produced is not being consumed at a local level but must be being moved beyond the Weald. This idea could be substantiated by the pottery discovered on sites such as at Bardown where there is a large amount of pottery from the areas surrounding the Weald as well as central Gaul, and the idea is discussed that this could be part of the return or incoming cargo with the iron being outgoing (Lyne, 2010).

Although there are a number of Roman roads identified throughout the Weald (Margary, 1965) these sites are more closely associated with waterways. The involvement of the CLBR would then make a better interpretation of transport from these sites. These waterways lead to two separate inland tidal bays indicating the potential direction of export from these sites out along the southern coast.

It is unclear if any of these newly identified proxies for control and military involvement are strong identifiers as there is not enough of a data set and understanding of features across the Weald. However, when combined on a site with an understanding of chronology they can be used for an interpretation with a degree of confidence. Moreover, with more investigation throughout the Weald into these proxies a deeper understanding can be gained and a better interpretations of sites made.

A large number of iron production sites across the Weald are small scale. As seen at Standen, there is little evidence of any organisation or finds of material culture to inform on the people running the site. If this is the norm across these small scale sites then it becomes very difficult to interpret with an certainty if there is any widespread control or organisation of these sites across the landscape.

10.4 Grassroots archaeology

Placing any archaeological site or process within a larger landscape setting is not possible without a substantive amount of investigative work. In many cases across the Weald, particularly with reference to the iron industry and the Roman era, a substantial part of this investigation and research has been undertaken by amateur archaeologists and research groups at a grassroots level, and this project has been hugely influenced and assisted by this network throughout the Weald.

The first and possibly most important influence is the fact that this project was set up and funded by the Wealden Iron Research Group in conjunction with Exeter University. Just like many walks of life, money in local and amateur archaeology groups is scarce, and therefore to use the available money to fund large research projects such as this one shows the passion to progress research and maintain or grow its momentum into the future.

This association led to the connection with other local amateur archaeology groups, mainly Hastings Area Archaeological Research Group (HAARG). These two groups alone have almost a century's worth of research between them and knowledge and resources stretching back further in time. With this in-depth local knowledge, site identification, further local contacts and access to sites becomes much easier allowing for a more efficient and integrated project giving it greater public interest and outreach.

To expand on this point both the sites used for case studies in this project were identified by these groups. HAARG had previously identified Chitcombe as a site of interest and were in the planning phase of a larger project into which they allowed this project to join. When a second site was needed for the project a member of WIRG, Jeremy Hodgkinson, introduced this project to Standen and contacts for the site which allowed the project to work on the site.

While these amateur groups conduct excellent research on a consistent basis they do not gain the same exposure as large professional or academic projects. It is hoped this project will in some form raise the awareness of some of the groups for future support and research.

10.5 Project Aims and Future Work

Over the past 100 years a solid foundation has been laid for the research of iron production throughout the Weald and it is hoped this project has contributed and highlighted elements that will inform on how to build on these foundations and continue the high level of research for the next 100 years.

10.5.1 Project Aims

The aims of this project were to:

- Gain an understanding of the social organisation of Roman iron production in the Weald

- Test methods for investigating iron production sites to calculate the horizontal and vertical extent of deposits with a focus on the technological waste deposit at both an intra- and inter- site level.
- Quantify and characterise technological waste to gain a true understanding of what forms the technological waste deposits and the development and changes that occurred in technological processes.

The aim to gain an understanding of the social organisation of Roman iron production in the Weald has been partially met by the identification of the working practice of the smelting workshop which has been attributed to early formation and control of iron production across the Weald by the Roman military and Empire. The aim has not been met in reference to small scale sites. The social organisation is still unclear. However, it is believed two new pieces of information have been gained to add information to these forms of sites. The first is the lower intensity factor and unclear stratigraphy leading to the interpretation that smelting is happening slower over time. Moreover, the identification of glassy and light slags shows a difference in the smelting process which has been identified elsewhere in the Weald potentially pointing towards a dissemination of processes across the landscape showing a wider social connection.

The aim to test methods for investigating iron production sites to calculate the horizontal and vertical extent of deposits with a focus on the technological waste deposit at both an intra- and inter- site level have been met. It has been shown through this project and others discussed that a variety of geoprospection techniques are adequate in the investigation of features on iron production sites. Earth Resistivity Tomography has been shown to be able to give an estimation of the depth of deposits and give an understanding of the structure of deposits in a two dimensional vertical slice. Induced Polarisation has been shown to give an estimation of the depth and structure of deposits while identifying specific material types. More development is needed on the understanding and interpretations of the results of this technique in the investigation of iron production sites. Electromagnetic surveys have be shown to assess relative depth of deposits according to frequencies. It has also shown the ability to identify features according to specific physical factors and potentially identify specific material types within the site. This technique needs further development for greater understanding and interpretations of the results of this technique in the investigation of iron production sites. Magnetometry has been shown to be able to map out magnetic features across iron production sites in the two dimensional horizontal plane allowing for a broad interpretation and understanding. With areas of high mixed magnetism it has been shown that the response measured by this survey type can get messy potentially obscuring other anomalies and features. Although the survey types have been shown to map deposits in three dimensions it is clear these are only broad understandings and at this point in their development cannot be used for highly accurate volume calculation. There is also an issue with investigating iron production sites due to the movement of material that should be taken into account when interpreting geo-prospection data.

The aim to quantify and characterise technological waste to gain a true understanding of what forms the technological waste deposits and the development and changes that occurred in technological processes has been met but there is wide ranging potential for further investigation and analysis. This project has shown how the systematic excavating and sampling allows for a macro-morphic analysis to give an understanding of the technological waste, its varieties, differences and similarities, which give an understanding of the technological processes that occurred on the site. It also allowed for the creation of an intensity factor which informs on the amount of smelting occurring on a site before repair or rebuild of the furnace.

10.5.2 Future work

Geo-prospection surveys

It is believed that this project has shown the importance of surveying iron production sites using a multi-technique approach in order to map and interpret anomalies and features. This allows for a faster and relatively in-depth assessment and interpretation of the type of site, including possible scale of production as well as understanding industrial practices, organisation, and control.

In future research in the Weald it is believed a wide scale survey project should be completed across the iron production sites of the Weald to give a better understanding of individual sites and landscapes as a whole, potentially adding new site classifications, and creating a larger database of anomalies and features for more accurate interpretation.

Excavation, material collection, and analysis of technological waste

The approach taken in this project, and others discussed, using spit excavation to investigate and sample the technological waste deposits for a quantitative assessment has been shown to produce a large amount of data on the process of smelting.

In future investigations into iron production in the Weald it is believed this form of spit excavation should be continued as it offers a standardised practice which allows for repeated consistent data capture. The material collection strategy used in this project (all material above 25mm, and 1kg per spit of material between 6mm and 25mm, and below 6mm, should be the minimum collected on a site for analysis. However, in future projects it would be recommended that a larger sample of small and matrix samples should be collected. The more material sampled the more time is needed for analysis and in all future projects this should be taken into consideration and factored into the project design.

It would also be recommended, based on this project, that large scale trenches should be excavated through the technological waste deposits to understand the true formation of these deposits and allow for systematic sampling regimes for dating evidence, such as charcoal for carbon dating, to understand the temporal relationships within the technological waste deposit.

In future analysis of technological waste in the Weald, it is believed that the types identified in this project should act as a guide. However, the non-biased approach used in this project should be continued for the identification of new and different types which could infer nuances of the smelting process.

The main reason for these recommendations is that it would create a landscape-wide data-set of technological waste deposits allowing for in-depth comparisons of a number of factors such as smelting practice, possible change in process through time, and the comparison of materials reflecting on intensity of production.

In this project macro-morphological visual analysis of samples was completed which is believed to have given enough information on a number of factors pertaining to the processes of smelting. However, it is believed that in the future a large scale microscopic and chemical analysis should be completed on samples of technological waste to give a deeper insight into smelting technology at a site level and compare this across the landscape to see if an understanding can be reached on organisation and control of sites through the physical smelting practice and processes.

Dating evidence

One of the most important research aims when looking at iron production across the Weald should be a mass dating of sites. Currently there are in the region of 1200 know sites attributed to iron production, including ore extraction. This is nearer to 950 looking at production sites across all time periods. Of these 950 production sites only around 400 have been dated. Any ability to truly understand how iron production has influenced the landscape and to assess production within and across a time period is lost when the number of sites could increase dramatically.

Wider landscape

It is clear from this project, and much of the research into iron production in the Weald, that each site does not exist as an individual or unique point in landscape, space or time. Therefore, although each site should be investigated to gain the most understanding possible, larger questions should always be maintained to position the site within the wider landscape.

The temporal dimension is ascribed as a factor here that should not be ignored in interpretation of the landscape of iron production in the Weald. The landscape is not static and influenced by a number of social changes from pre-Roman Iron Age, through the Roman era and into the post Roman. For this reason time should always be a factor in interpretation of the landscape.

There are a number of sites identified throughout the Weald that have been dated to the Iron Age period (WIRG, 2019) and could be interpreted to be the area mentioned by Caesar in his writings. The early dates from Chitcombe and possible early dates and evidence of Iron Age occupation from Footland Farm (Cornwell, Cornwell, and Padgham, 2013) shows these Roman iron production sites are being formed as early as the point of the Claudian invasion. To set up such large industrial production centres there must have been a level of local knowledge to know where large ore outcrops were present in order to supply these sites. There are a number of possibilities to explain this. One is that within the military or Roman contingent entering Britain during or closely after the invasion were a set of specialists who could quickly identify the best areas to set up large industrial smelting sites. Another is that these sites are based on the same sites as earlier Iron Age iron production with the locals either fleeing and the Romans directly working the areas themselves or locals are being employed by the Romans in some form with their local knowledge of material. Is this area friendly and welcoming to the Romans as they have spent the last 100 years being slowly annexed and become Romanised to an extent? This large change in the landscape is one question that should try to be addressed in future projects.

There is very little evidence for iron production in the post Roman early Saxon period. This shows a dramatic change in the social landscape across this period which is another aim that should be addressed in future research projects.

It is believed, based on this project, that there is one aim that deserves special attention in future investigations. This is a more in-depth assessment and excavation of the smelting workshops. This would be to understand their formation, form, and structures. This is to identify if all four highly magnetic anomalies have been correctly interpreted as furnaces, and if it is possible to interpret how many were in operation at one time. Also to see if there are any structures such as buildings within the ditched enclosure. This would give a much clearer picture of the organisation and control of production and allow a better interpretation of others identified through geo-prospection surveys.

Archaeologically and historically the Weald has been seen as a centre for iron production and has been typecast as such, particularly within the Roman period where there has been very little evidence of major settlement or material culture identified. While the case stands that material production in the area is dominated by that of iron there is also tile production, as seen at Northiam (Cornwell and Cornwell, 2017) and Castle Croft (Cornwell, Cornwell, and Padgham, 2007). Settlement across the area ranges from farmsteads, to higher status settlement as seen at Kitchenham farm (Cornwell and Cornwell, 2007), and a possible small-town with possible industrial specialisation (Burnham, 1990), which could be a possible interpretation of new surveys from Footland Farm (Cornwell, Cornwell, and Padgham, 2013). This shows that when looking at iron production sites they should be assessed and interpreted as part of a much wider landscape, not just of iron production but of habitation, transport and the production of other materials. This should build a picture of a rich and diverse landscape of life rather than a mono-landscape of single production.

A Case Study 1 - Chitcombe - Geo-prospection

A.1 Raw Data Images

A.1.1 Magnetometry

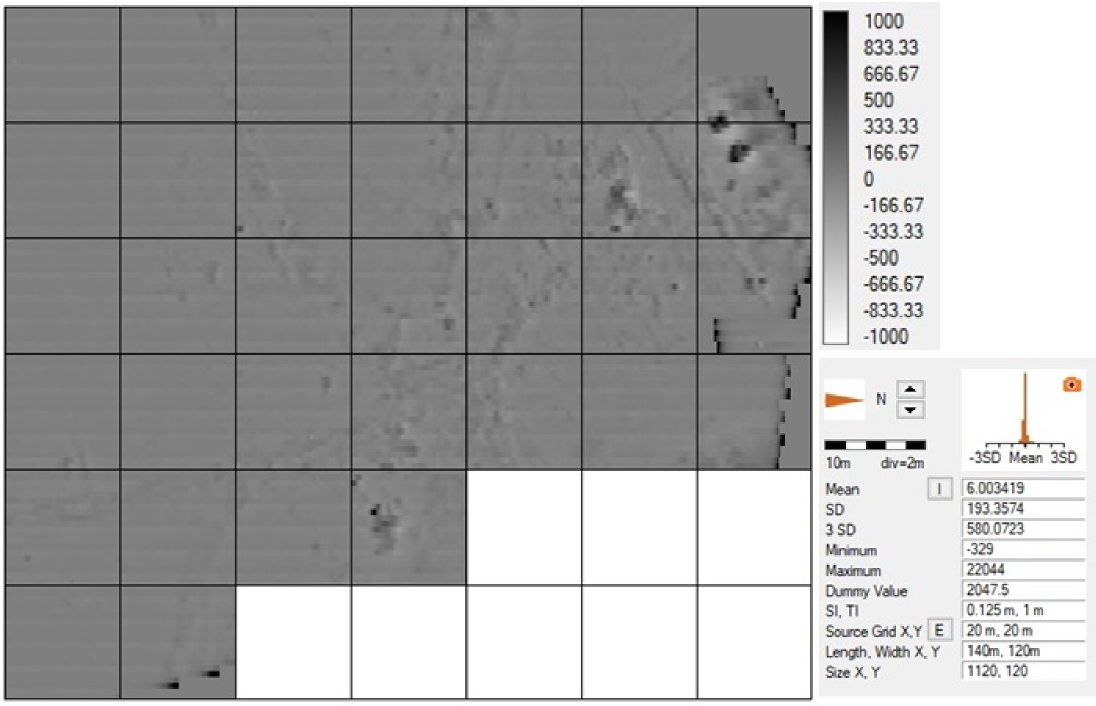


FIGURE A.1: Magnetometry Field 1 raw data

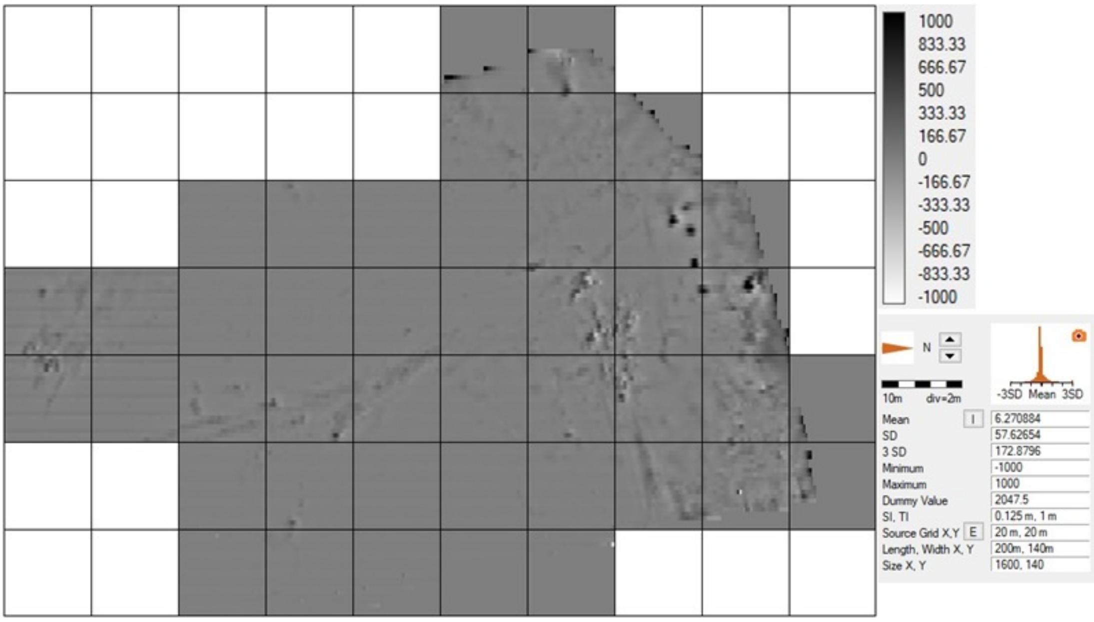


FIGURE A.2: Magnetometry Field 2 raw data

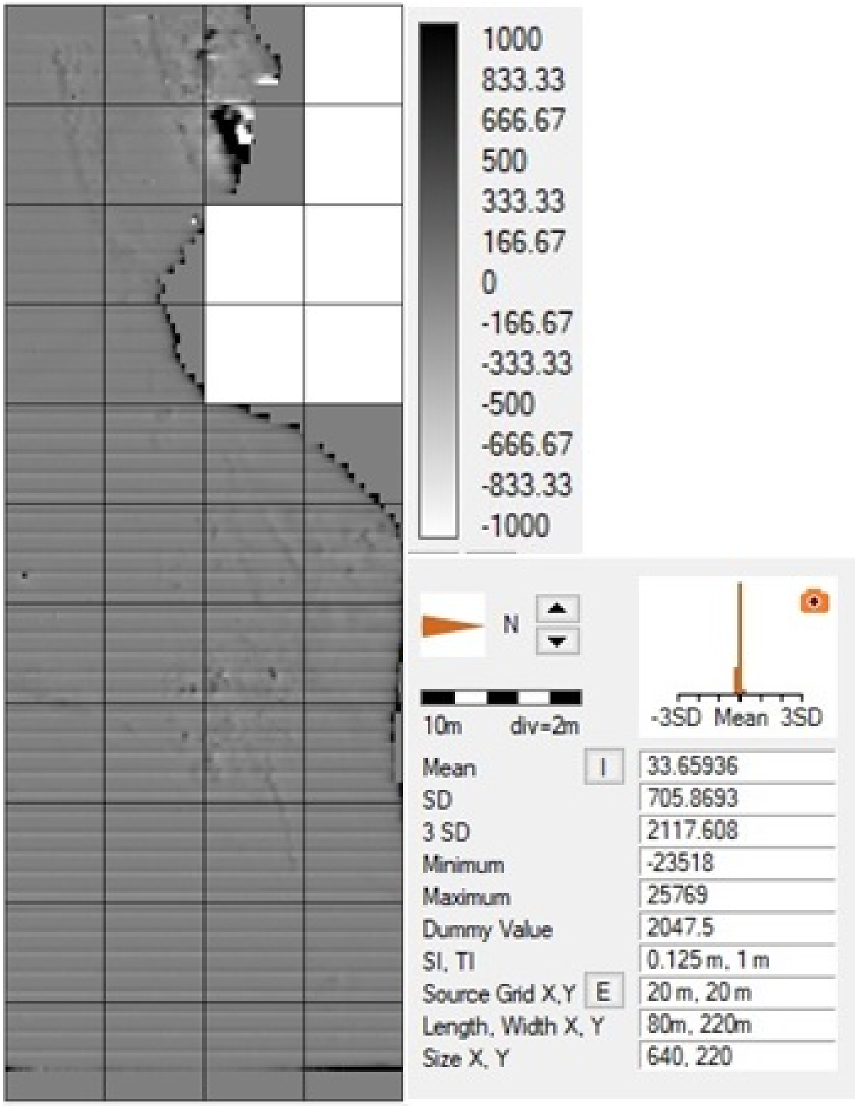


FIGURE A.3: Magnetometry Field 3 raw data

A.1.2 Earth Resistivity Tomography

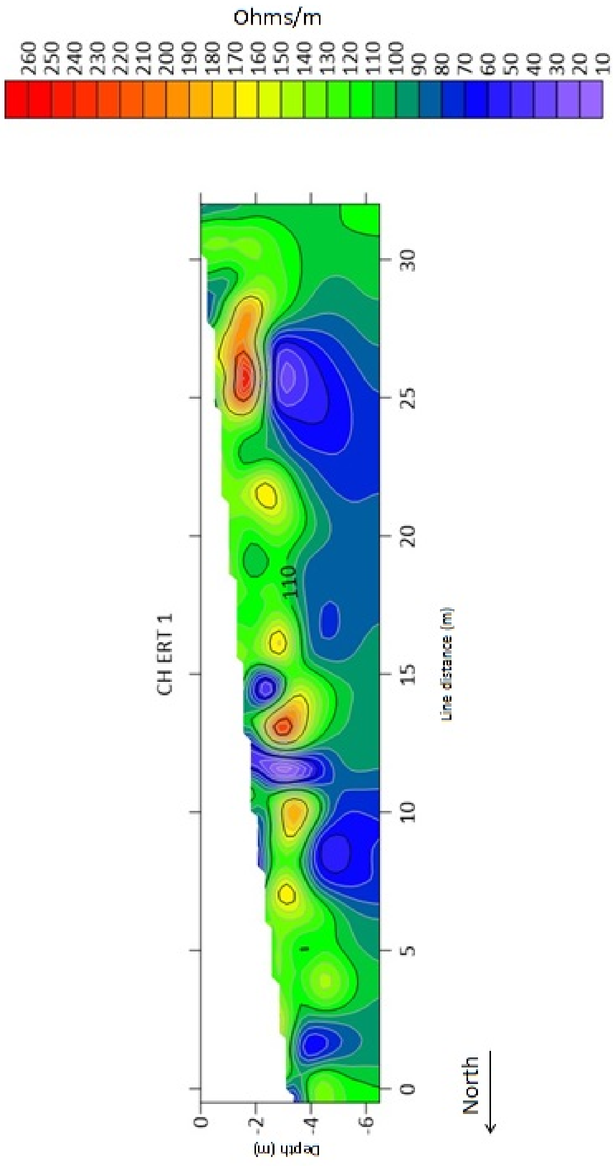


FIGURE A.4: Earth Resistivity Tomography Line 1 Raw Data

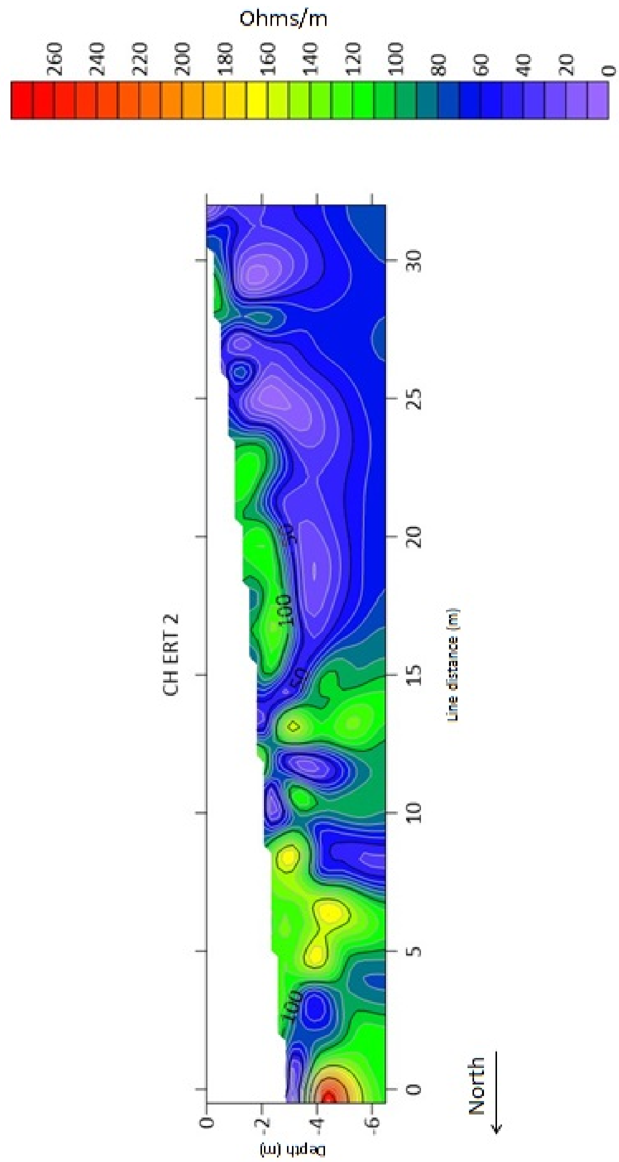


FIGURE A.5: Earth Resistivity Tomography Line 2 Raw Data

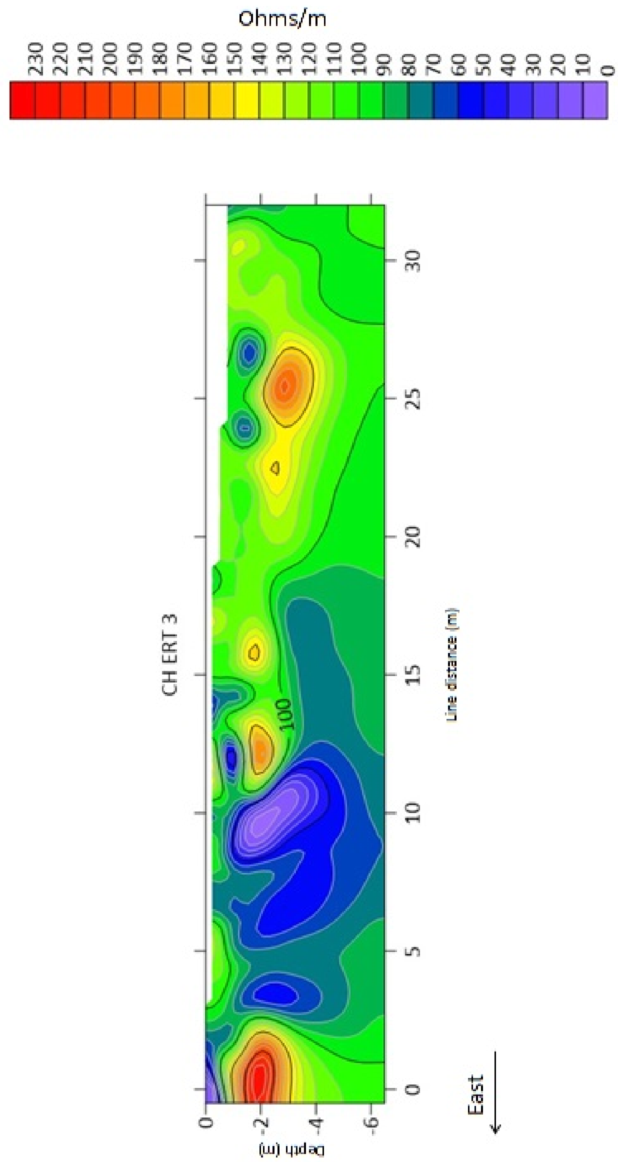


FIGURE A.6: Earth Resistivity Tomography Line 3 Raw Data

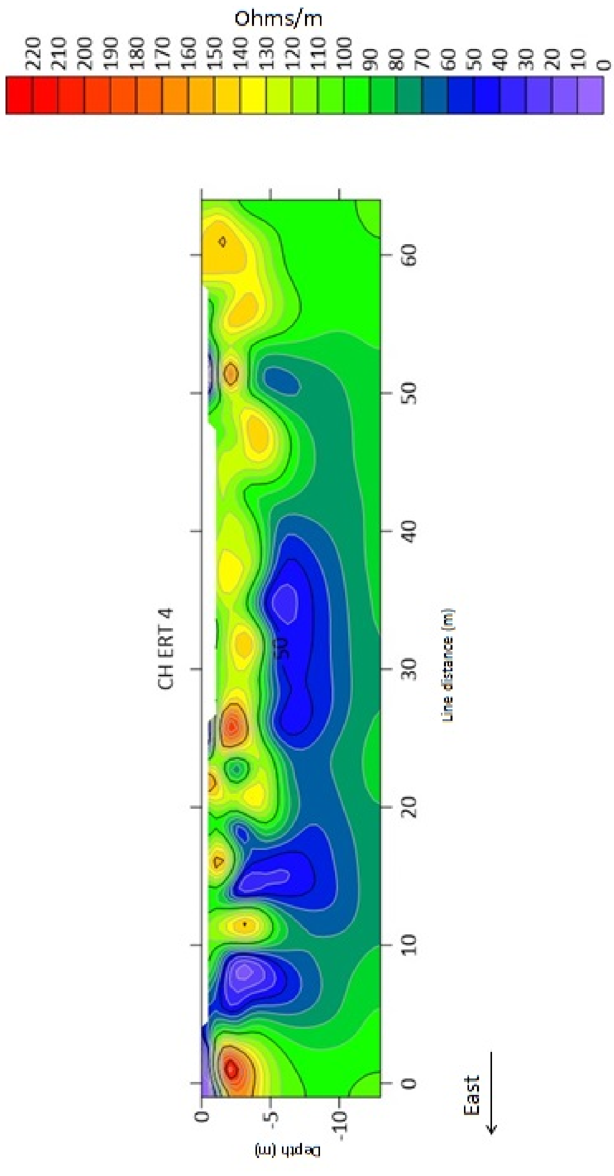


FIGURE A.7: Earth Resistivity Tomography Line 4 Raw Data

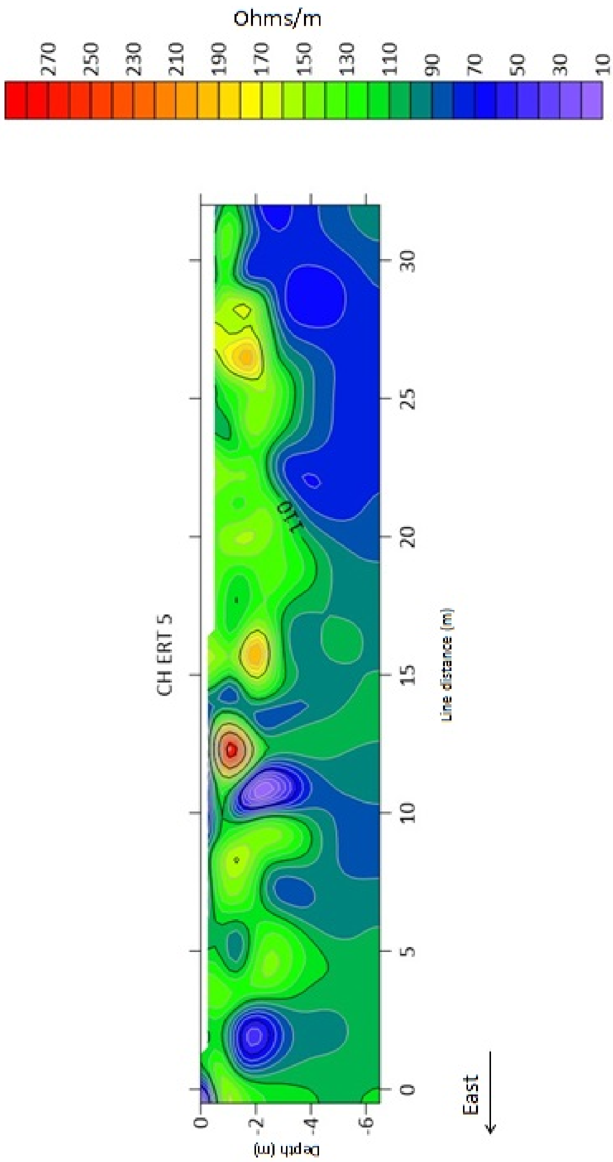


FIGURE A.8: Earth Resistivity Tomography Line 5 Raw Data

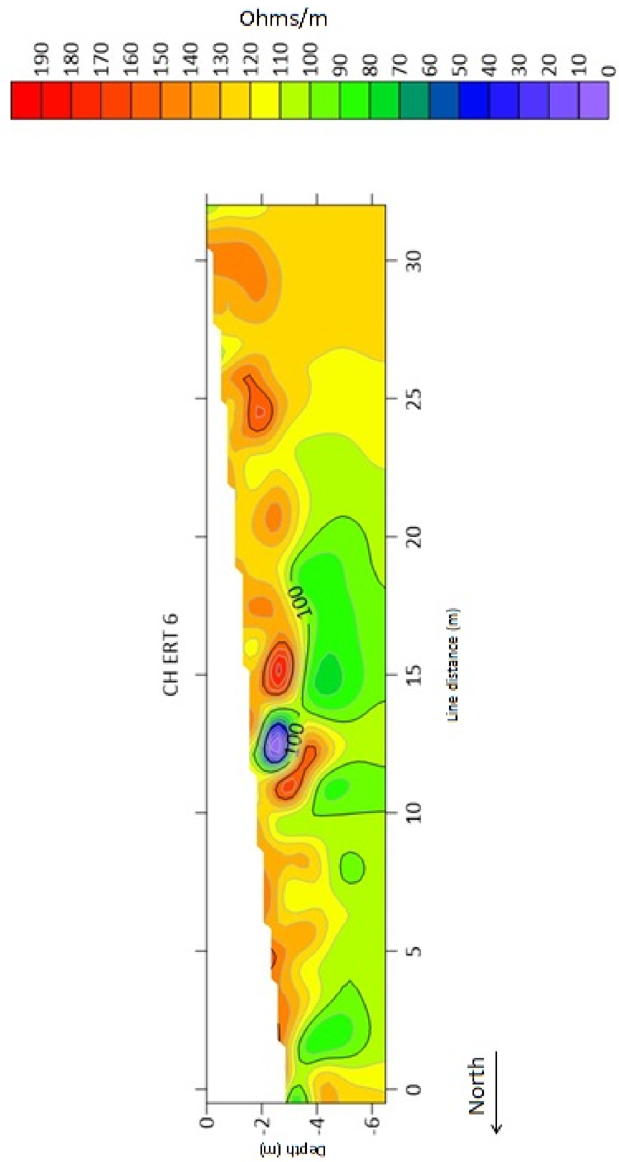


FIGURE A.9: Earth Resistivity Tomography Line 6 Raw Data

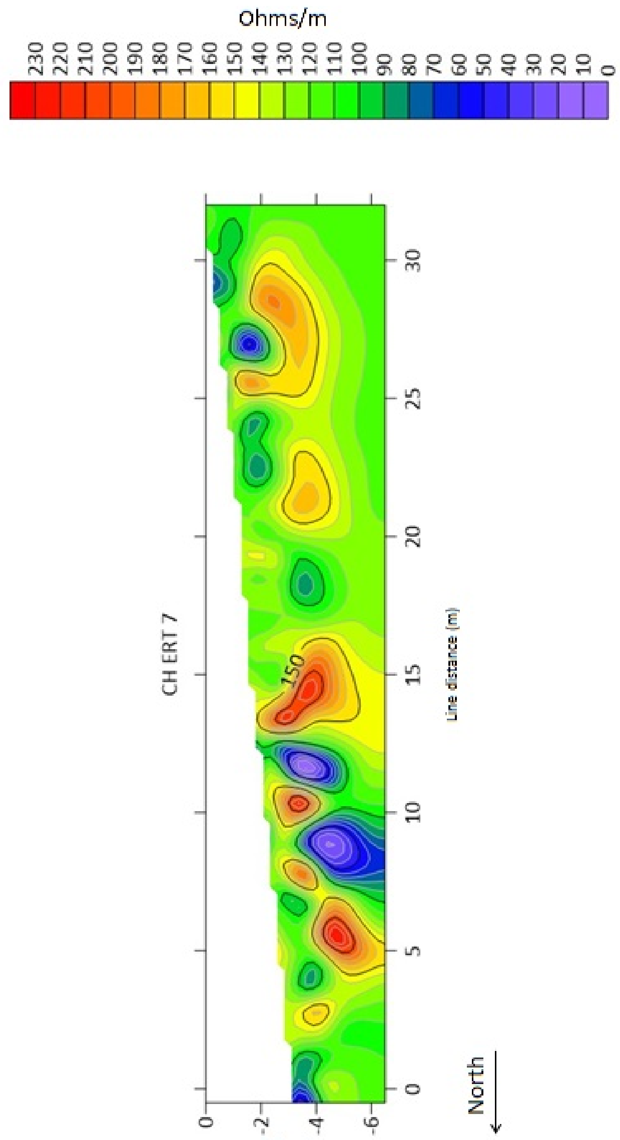


FIGURE A.10: Earth Resistivity Tomography Line 7 Raw Data

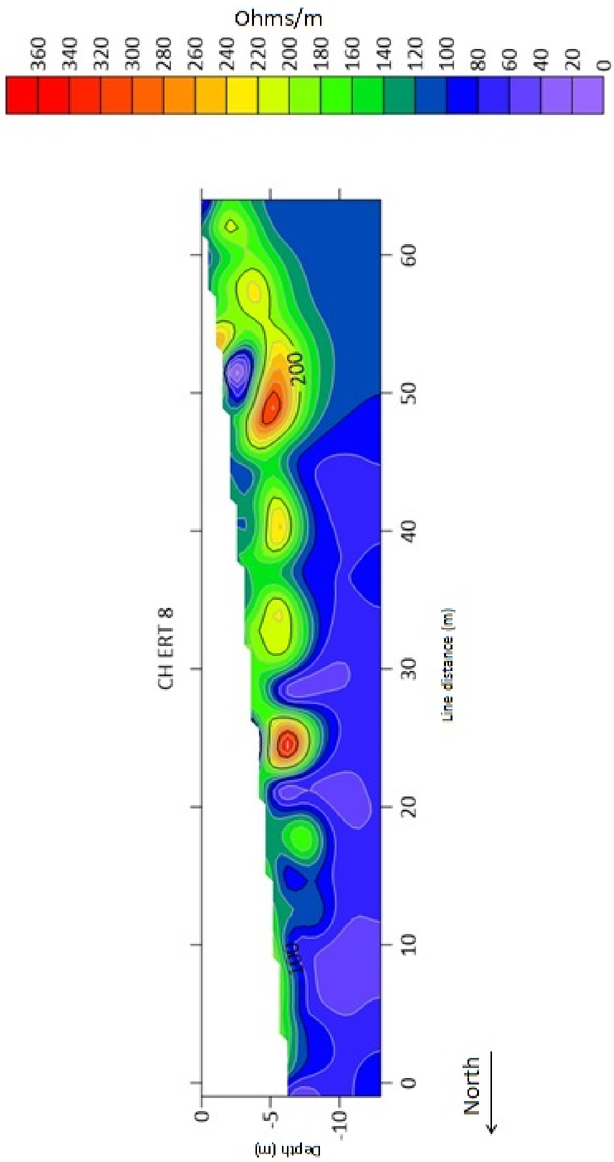
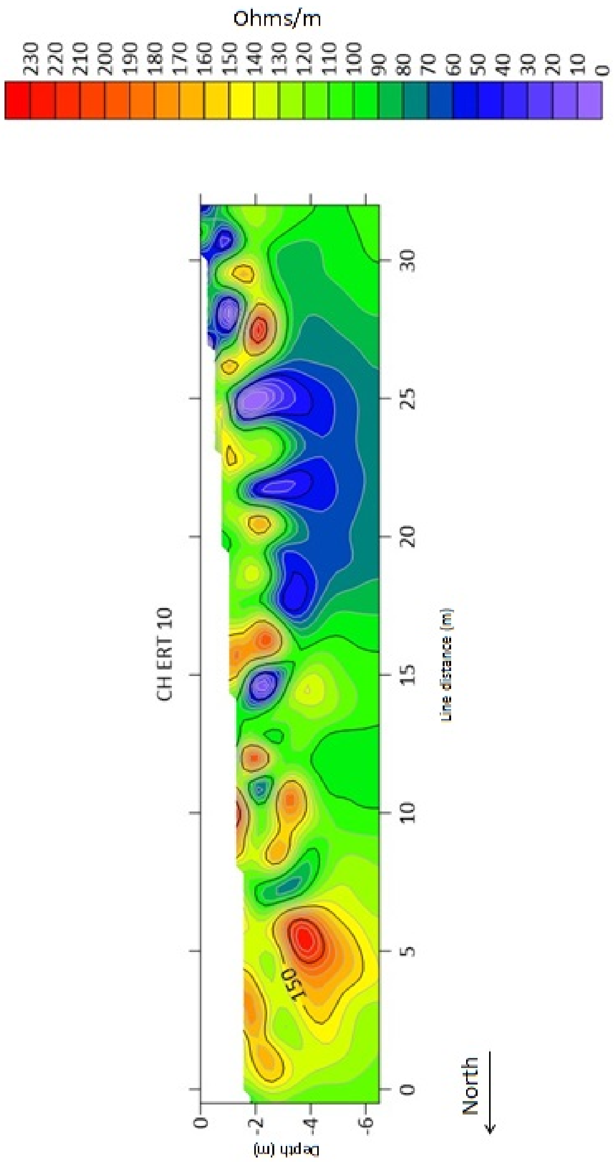


FIGURE A.11: Earth Resistivity Tomography Line 8 Raw Data



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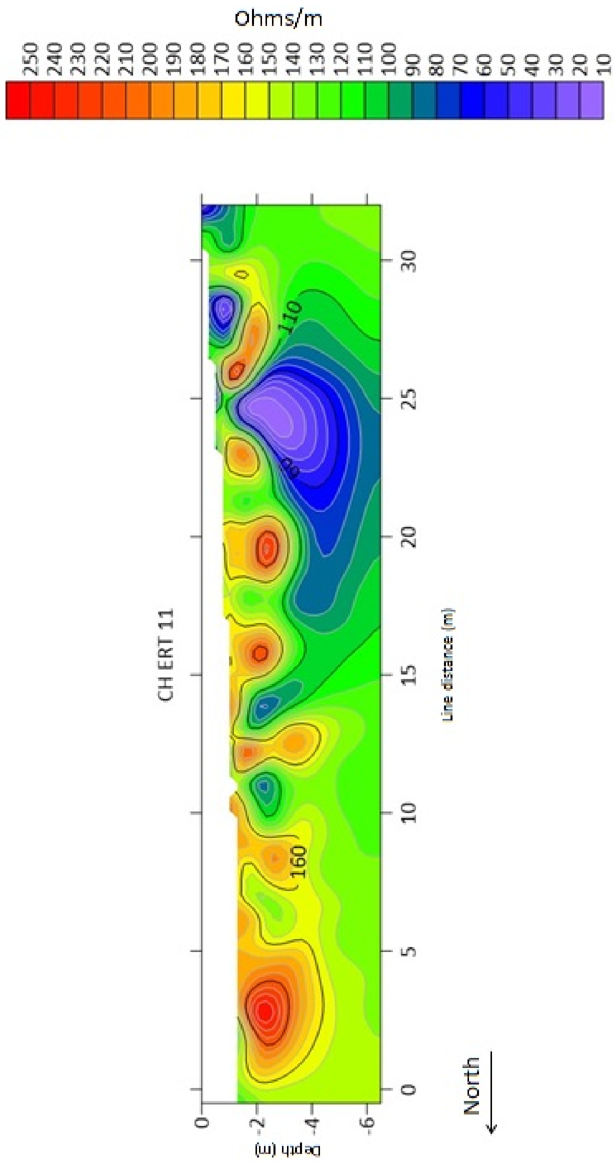
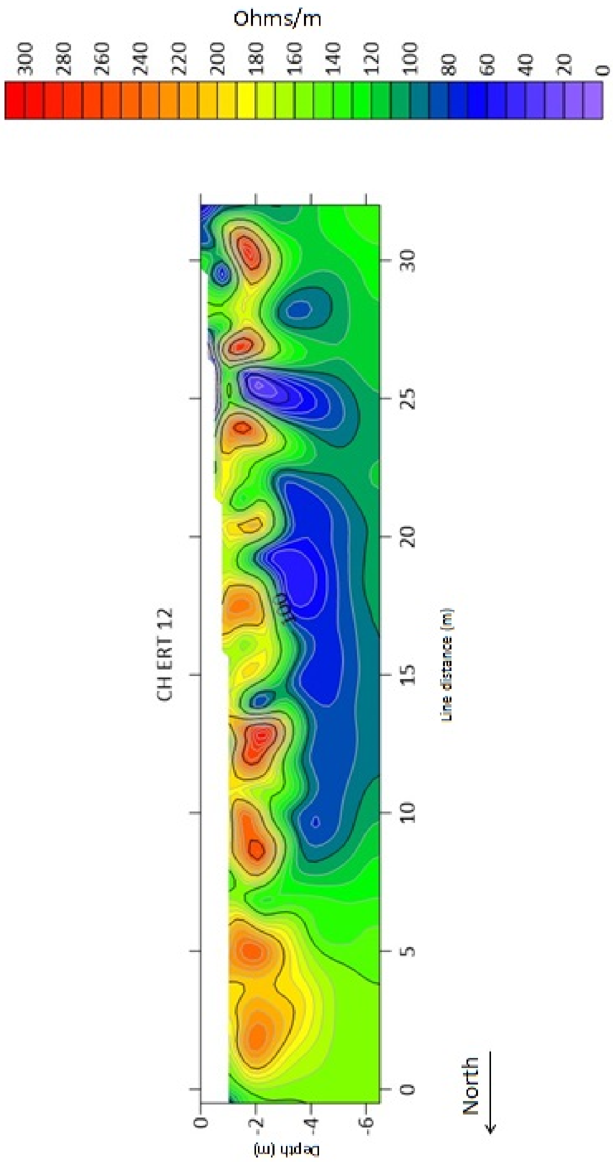


FIGURE A.13: Earth Resistivity Tomography Line 11 Raw Data



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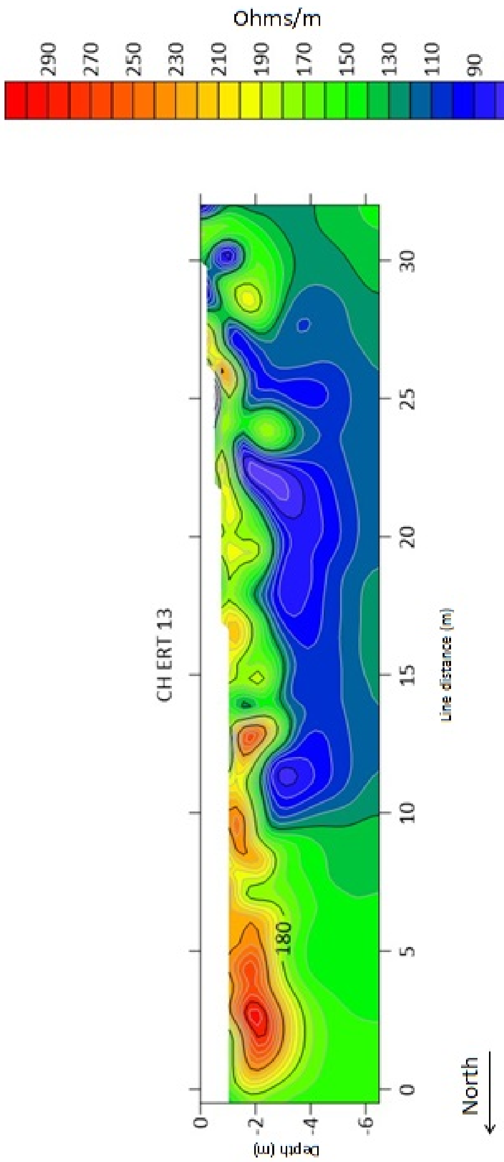


FIGURE A.15: Earth Resistivity Tomography Line 13 Raw Data

A.1.3 Induced Polarisation

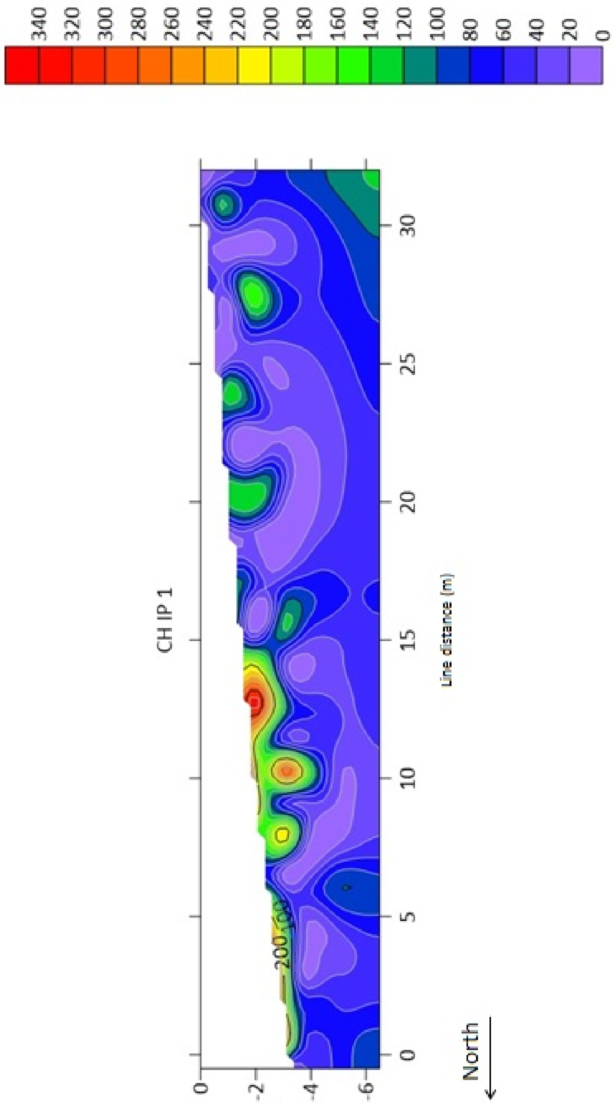


FIGURE A.16: Induced Polarisation Line 1 Raw Data

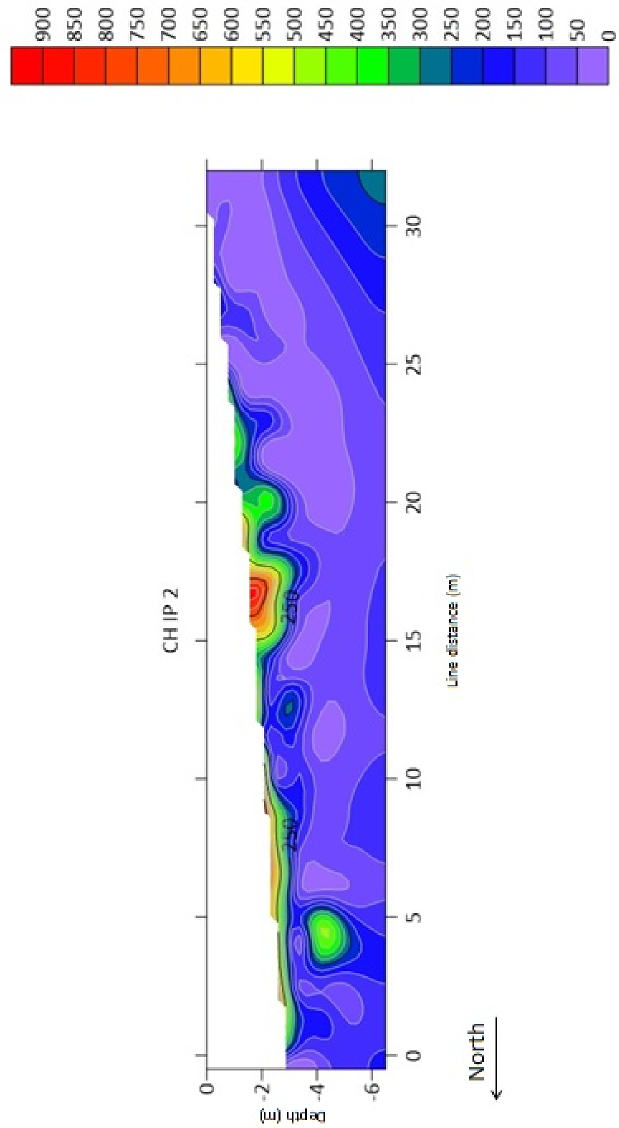


FIGURE A.17: Induced Polarisation Line 2 Raw Data

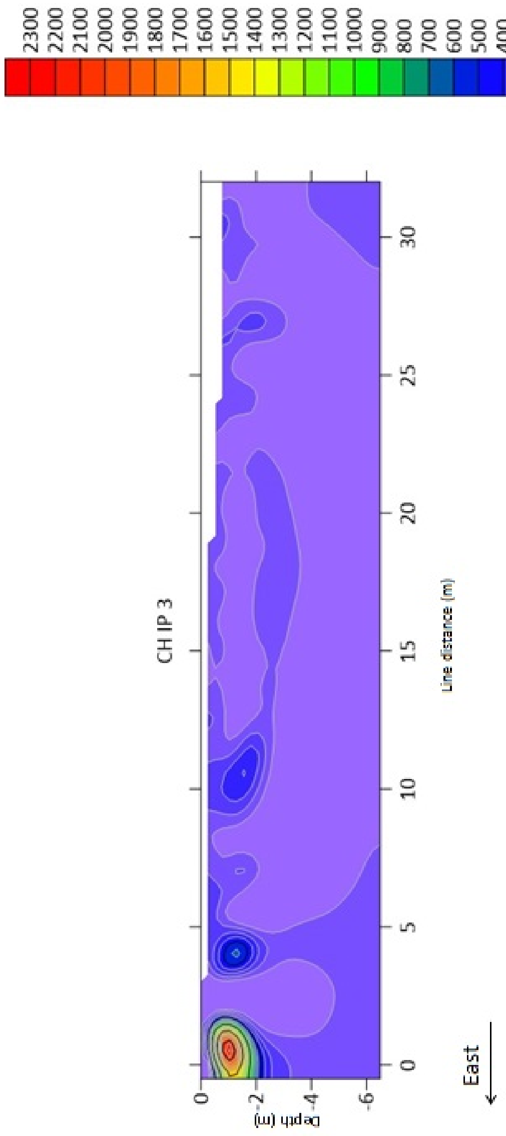
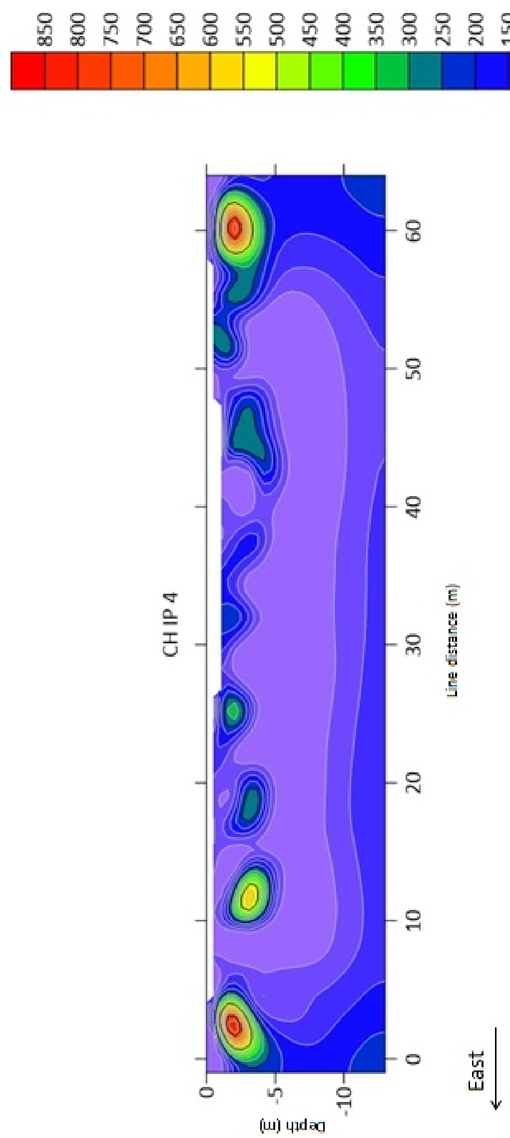


FIGURE A.18: Induced Polarisation Line 3 Raw Data



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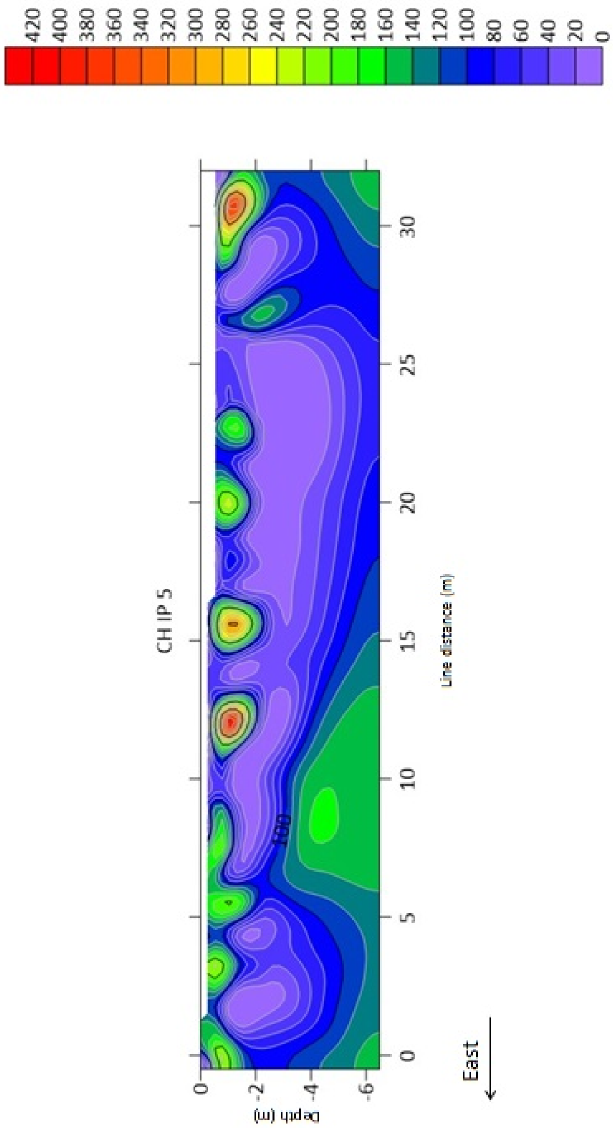
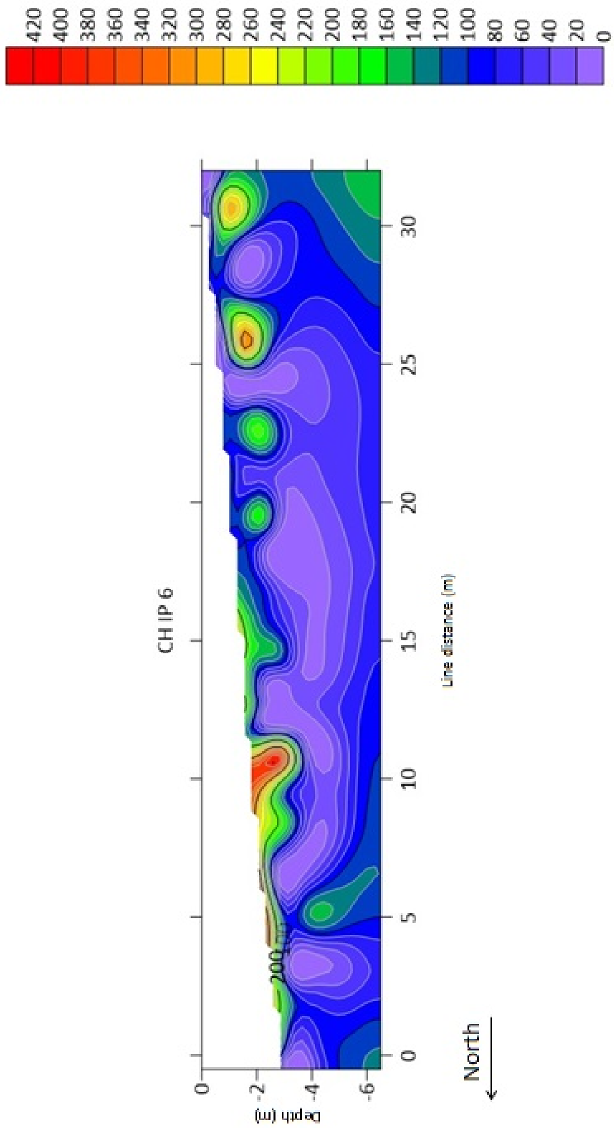


FIGURE A.20: Induced Polarisation Line 5 Raw Data



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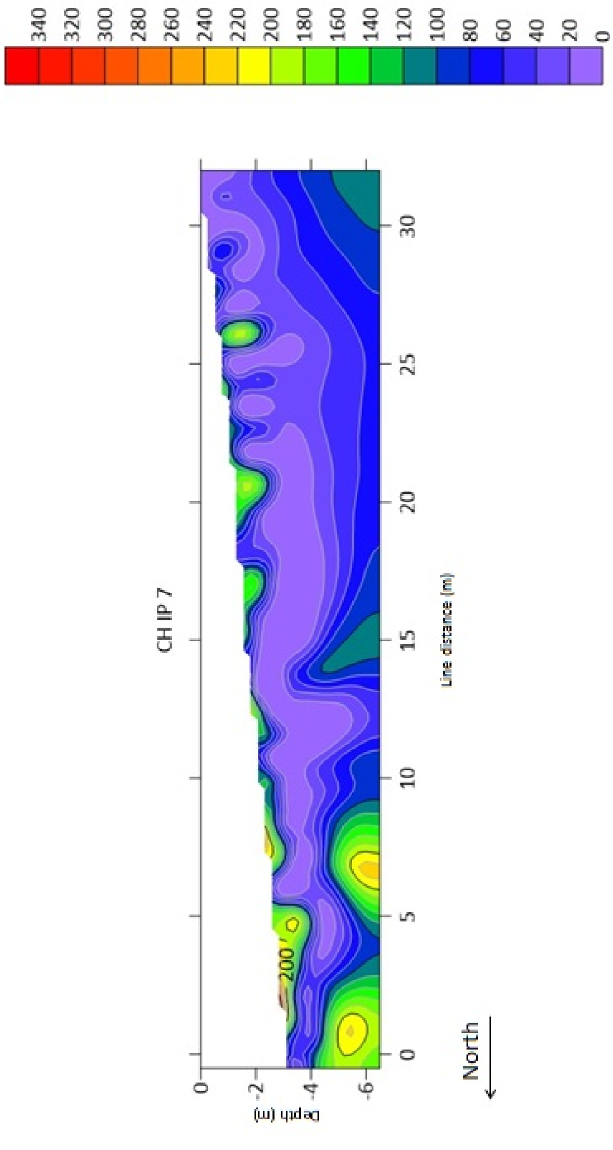
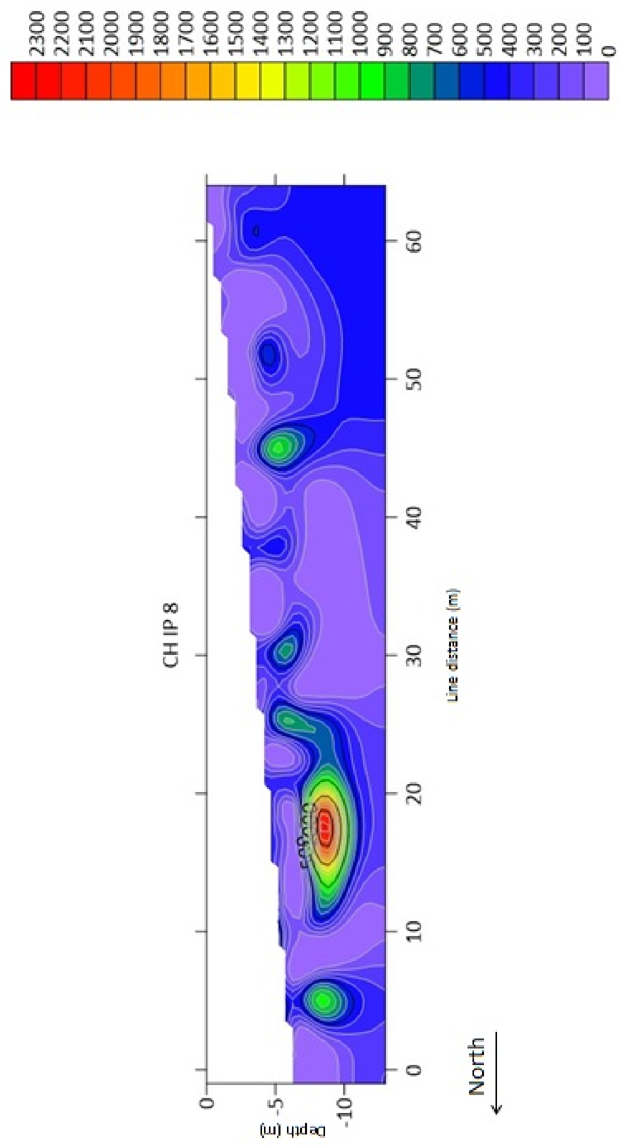


FIGURE A.22: Induced Polarisation Line 7 Raw Data



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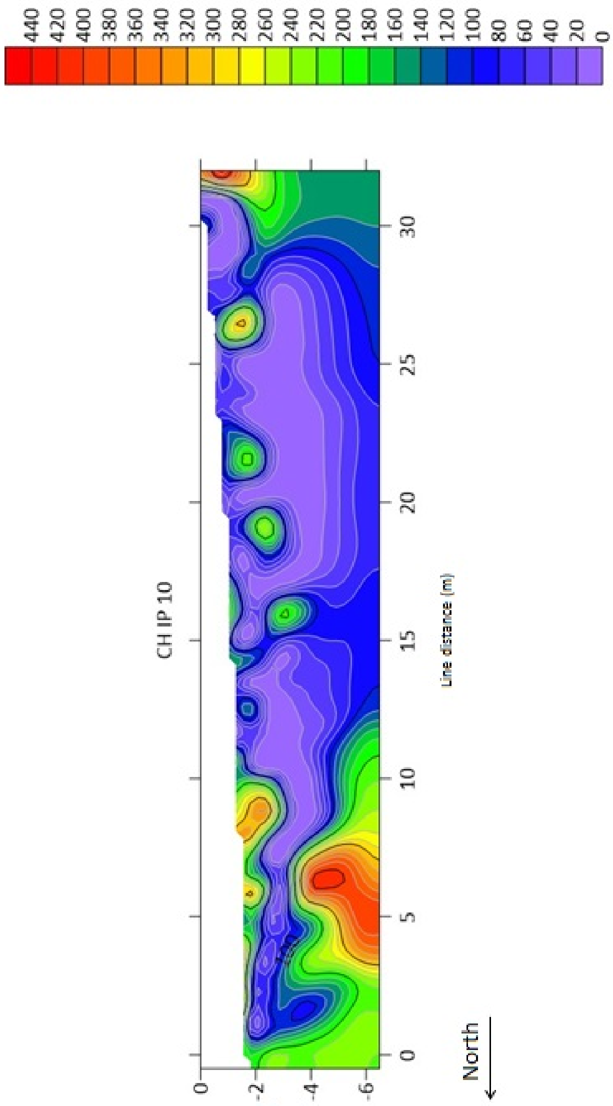

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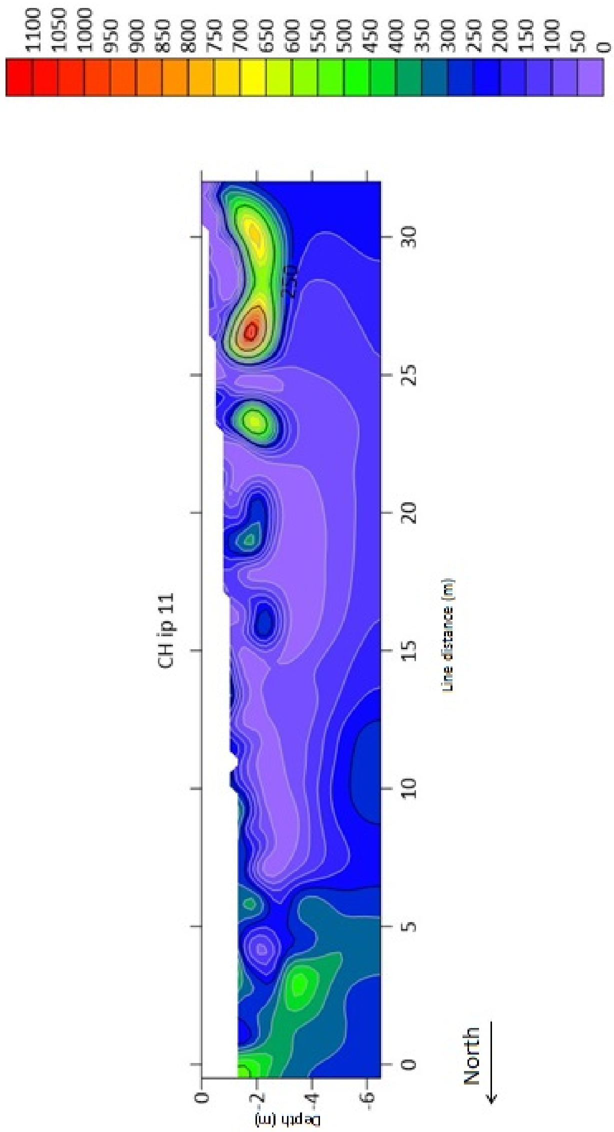

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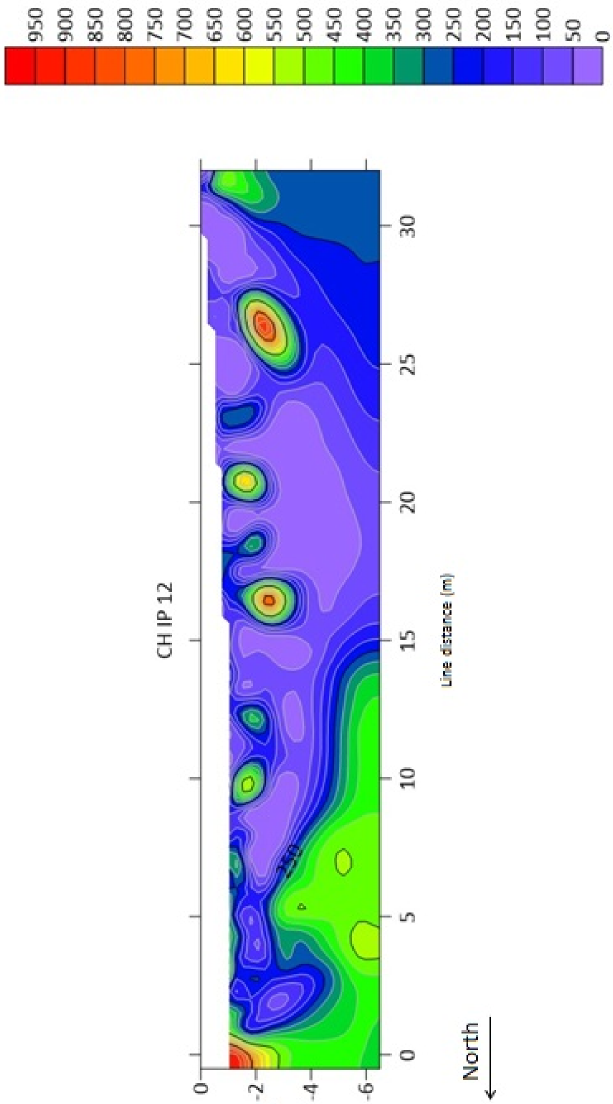

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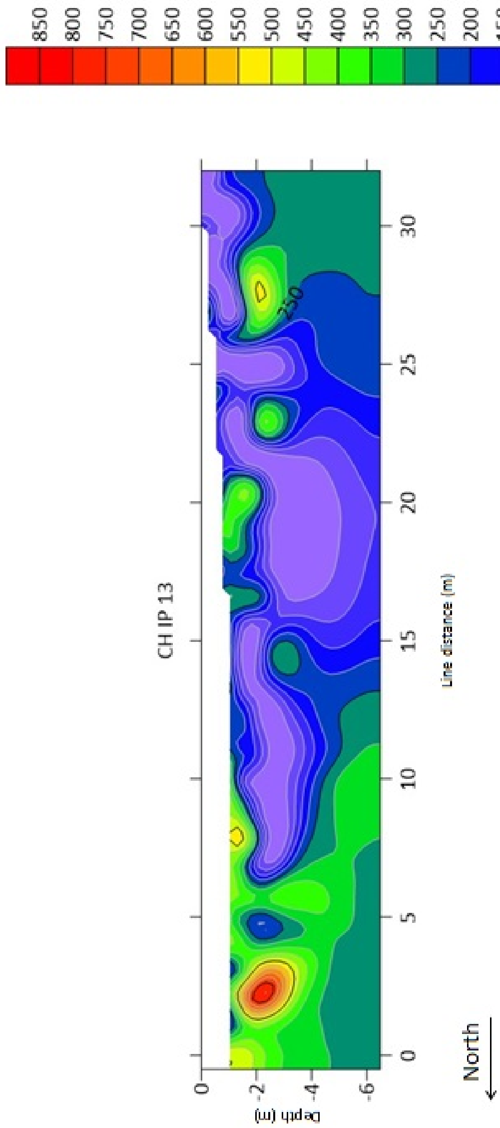

FIGURE A.27: Induced Polarisation Line 13 Raw Data

A.1.4 Electromagnetic

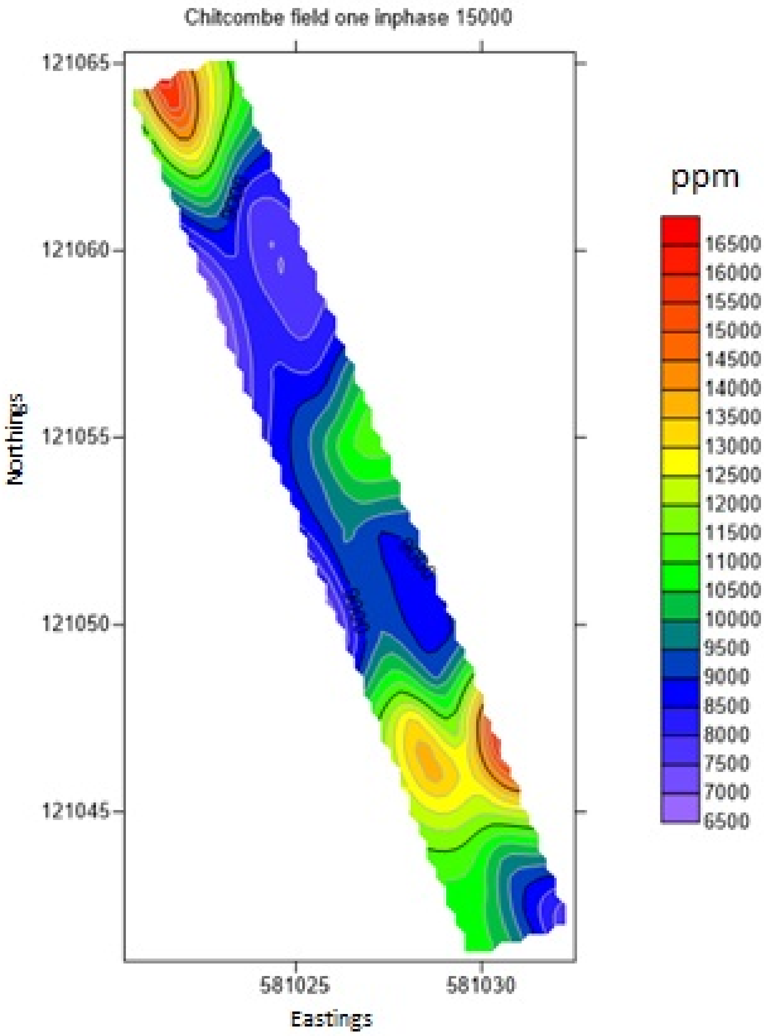

FIGURE A.28: In-phase 15kHz Field 1

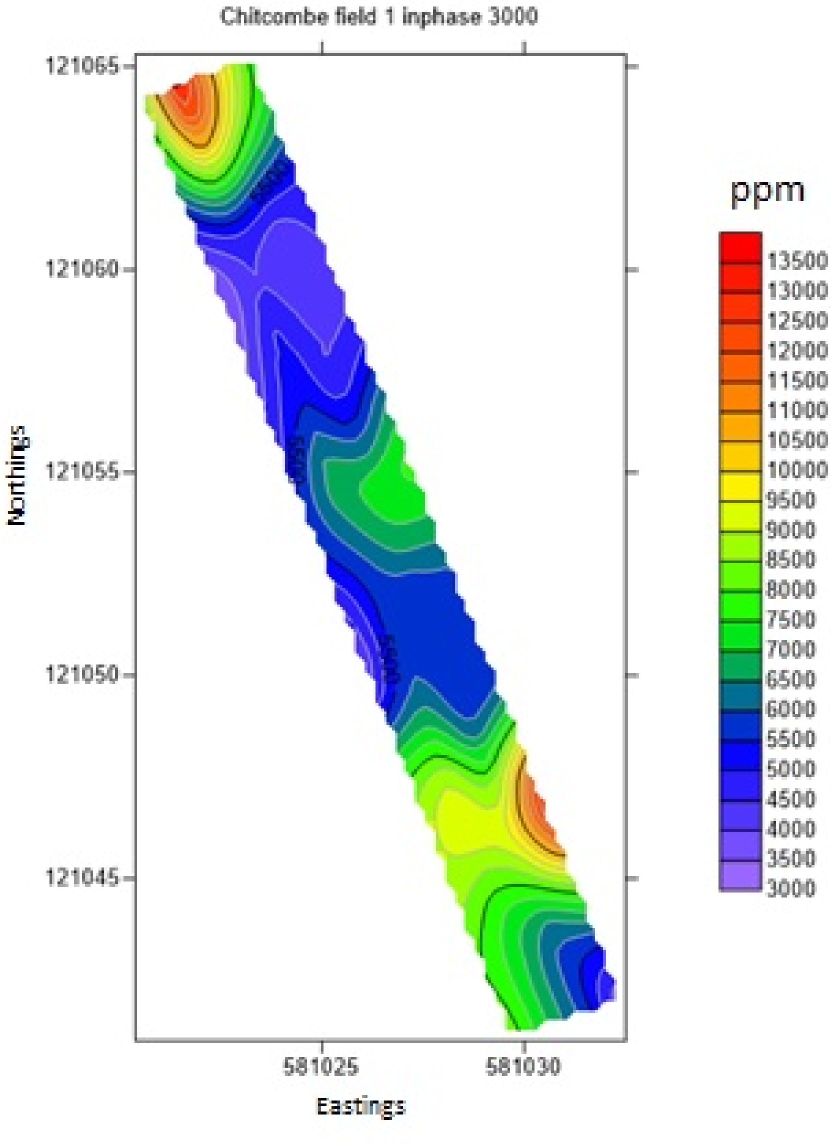

FIGURE A.29: In-phase 3kHz Field 1

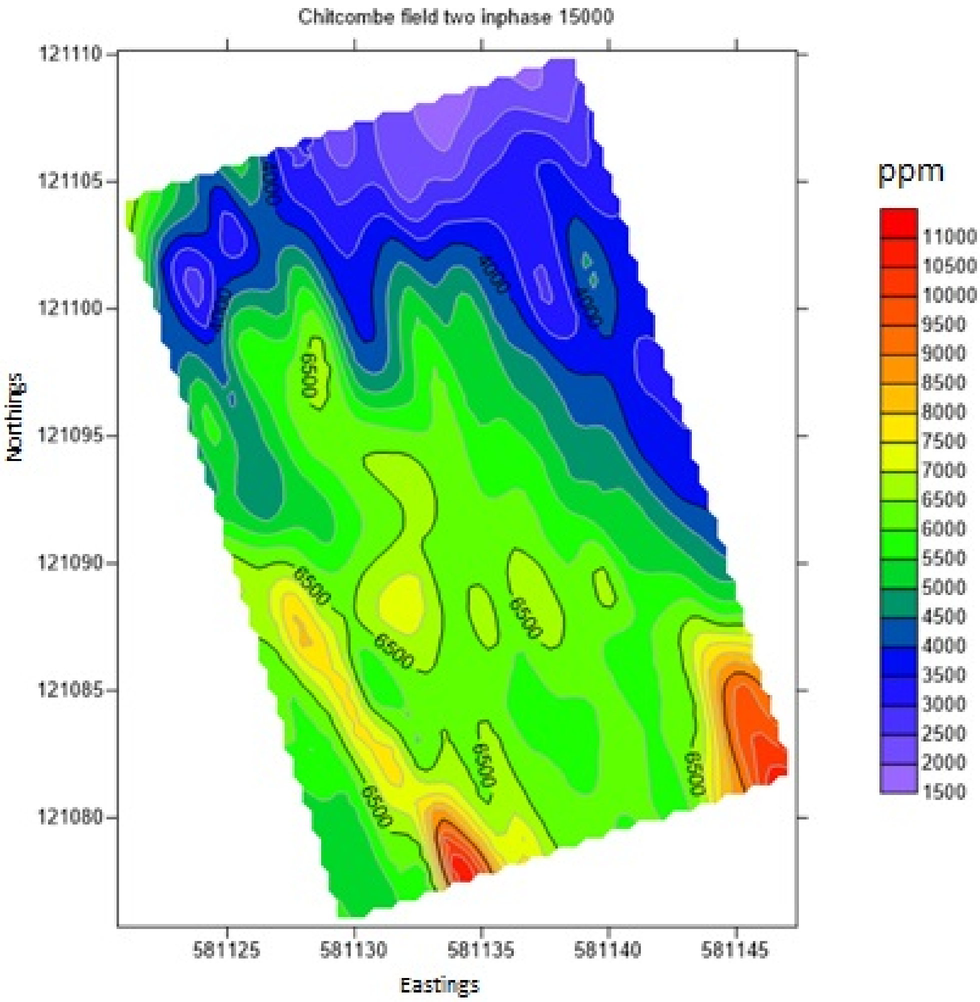

FIGURE A.30: In-phase 15kHz Field 2

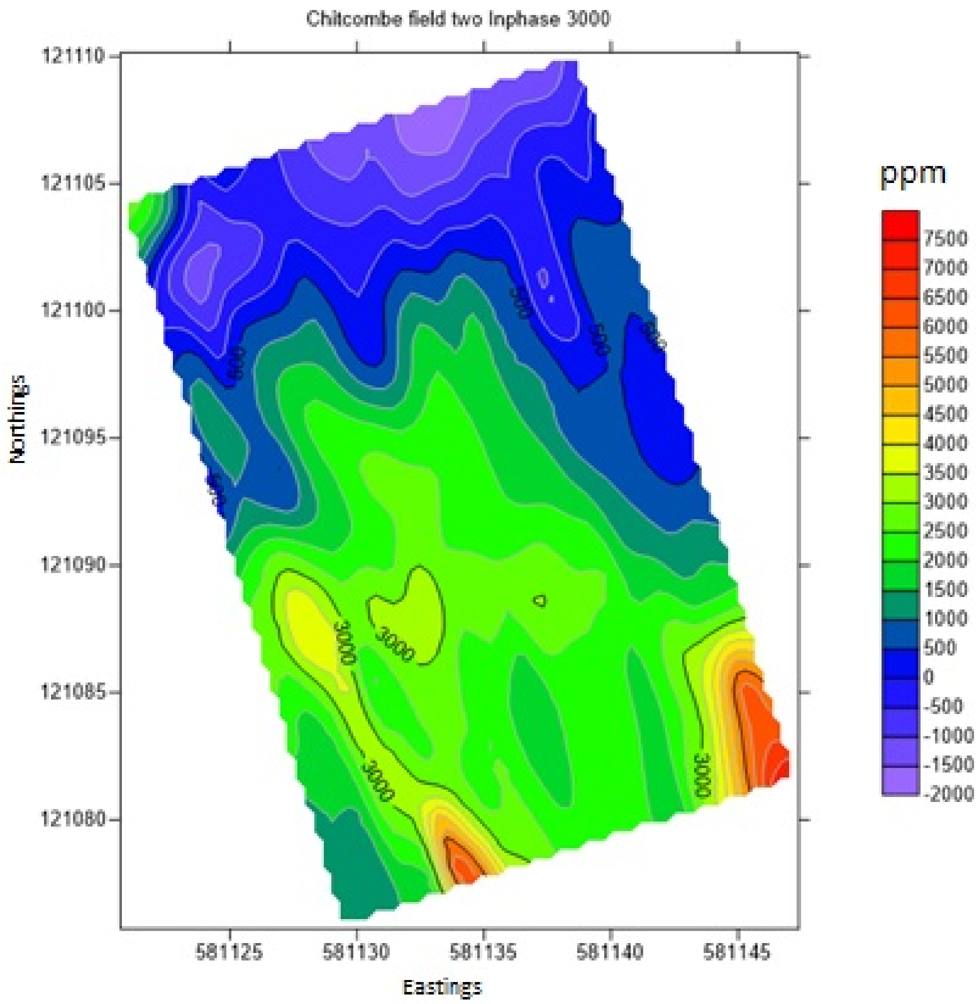

FIGURE A.31: In-phase 3kHz Field 2

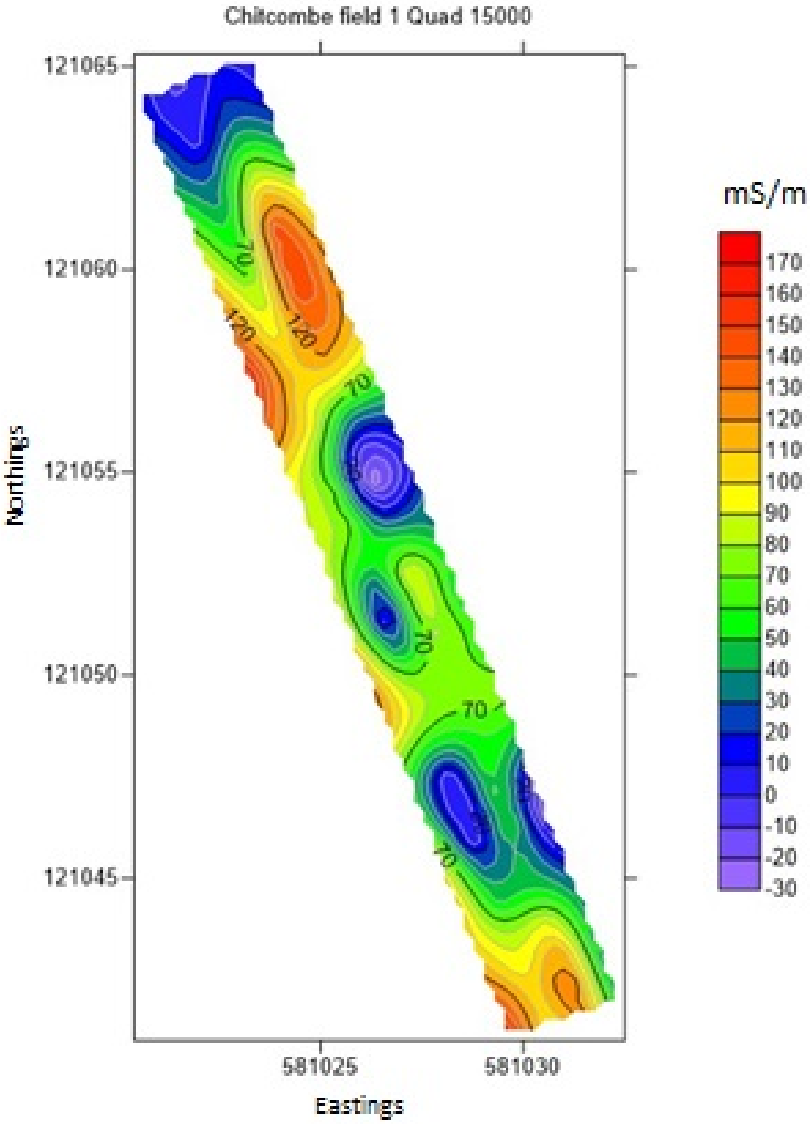

FIGURE A.32: Quadrature 15kHz Field 1

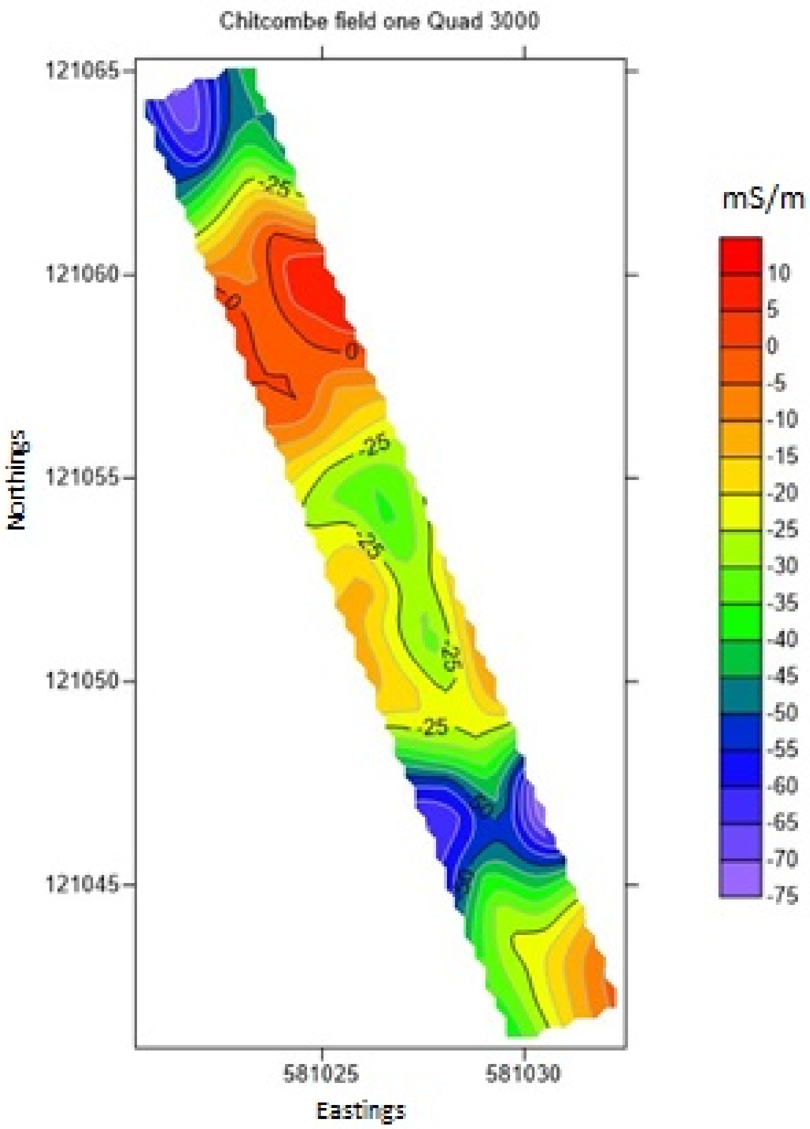

FIGURE A.33: Quadrature 3kHz Field 1

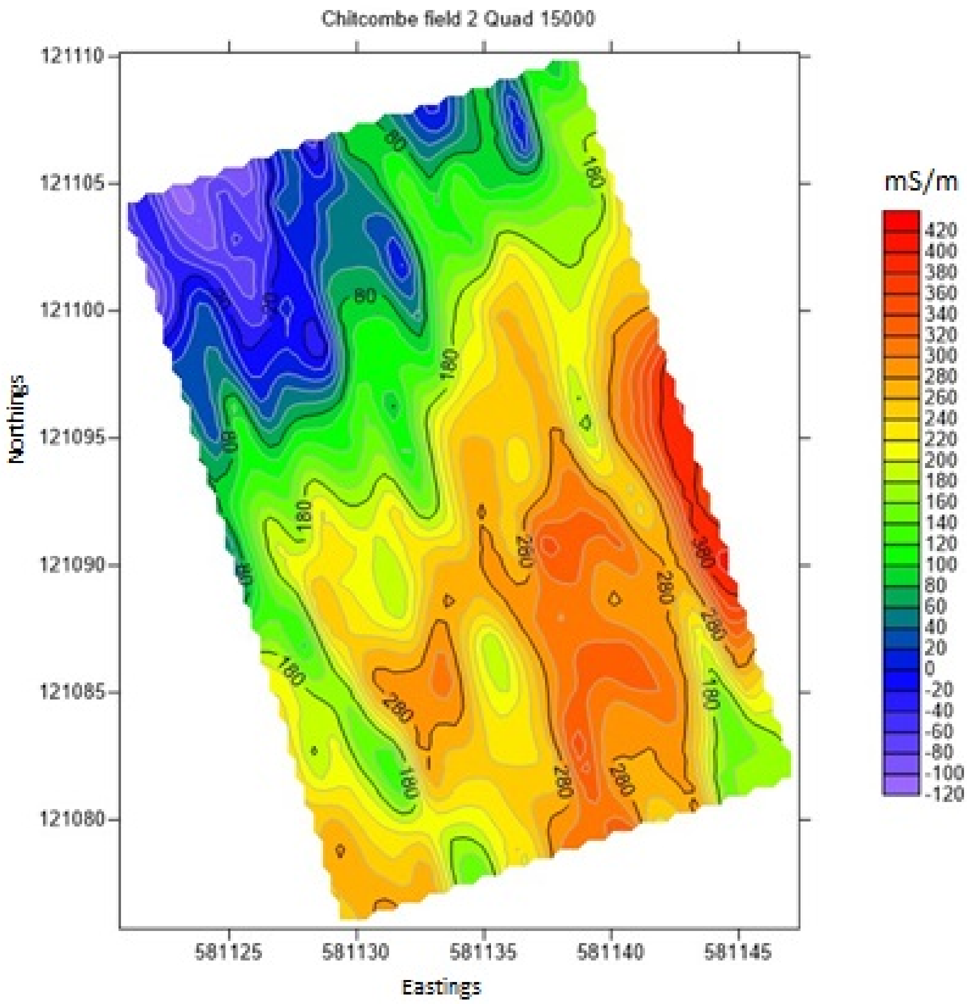

FIGURE A.34: Quadrature 15kHz Field 2

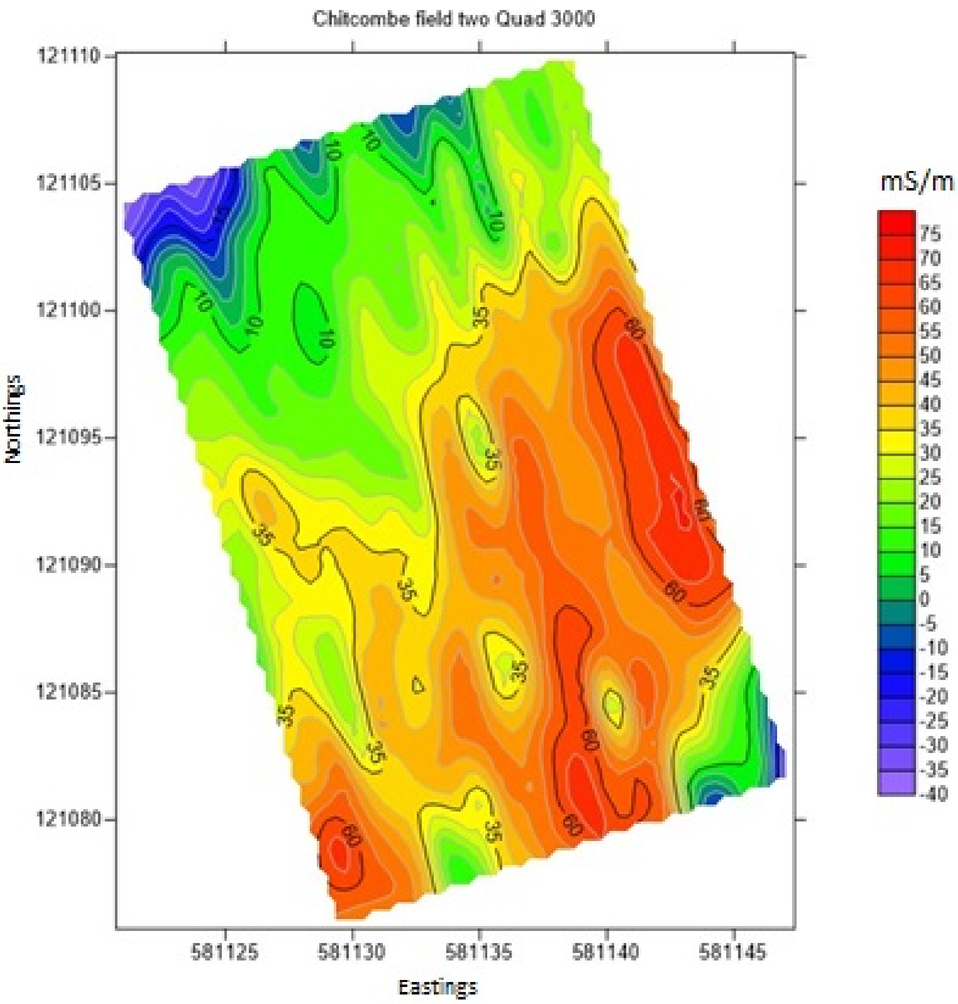

FIGURE A.35: Quadrature 3kHz Field 2

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A.2 Annotated Images and Discussion

A.2.1 Magnetometry

Field 1

Anomalies:

Furnace (RED) Up to four high magnetic anomalies with readings up to 780nT being round or oval in shape, forming a straight line.

Ditch/Linear (Green) Two linear anomalies which intersect at a right angle at 581021E 121052N with readings up to 163nT. Ditch creating smelting workshop. A number of other linear anomalies to the northern-half of the survey represent ditches or structures associated with the working area

Track (Purple) A number of mixed magnetic anomalies all converging on an area centred on 581070E 121015N are interpreted as pathways and have a variety of readings from -49nT to 81nT.

Posthole/pit (Orange) Two increased magnetic anomaly measuring 427nT (positioned 581031E 121066N) interpreted as a large post-hole in the smelting workshop.

Modern (Yellow) caused by metal fence around field

Primary deposition (Light blue) A large highly magnetic anomaly measuring 412nT at 581034E 121047N, represents primary deposit in the working area. Primary deposits to the north of the furnaces represent the start of the TWD.

Secondary deposition (Dark Blue) Secondary deposition of technological waste deposited across the site with no clear interpretation

Other observations:

-One of the trackways referenced in extends into Field 2.

Associations:

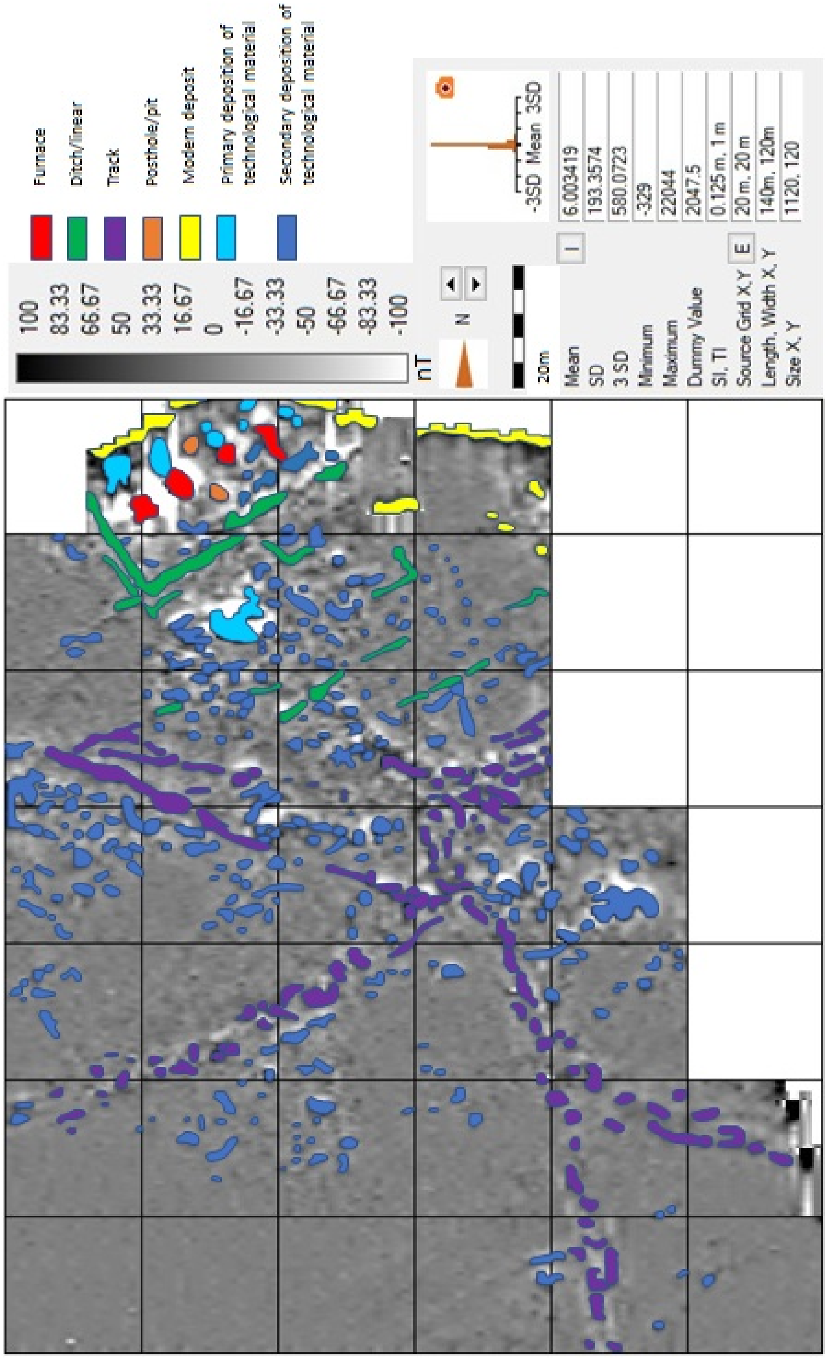

FIGURE A.36: Magnetometry Field 1 Normalised and Annotated data

Field 2

Anomalies:

Furnace (RED) Four circular high magnetic anomalies positioned in the centre north of the survey

Ditch/Linear (Green) Linear feature just to south of furnace the ditch forming the smelting workshop. Set of linear anomalies to the centre-east of the survey represents an enclosure area.

Track (Purple) multiple tracks heading in all directions with the main east west track acting as an apparent division with all iron production occurring to the north

Posthole/pit (Orange) set of six large postholes in north east corner of field possibly representing a large structure.

Modern (Yellow) caused by metal fence and gates

Primary deposition (Light blue) area to the north of furnace represents TWD. Area across and to the north of the track interpreted as a working area due to the high magnetism.

Secondary deposition (Dark Blue) Secondary deposition of technological waste deposited across the site with no clear interpretation - caveat should be placed here for the north-east corner of the survey which has been interpreted as a possible made surface using technological waste but this is still secondary deposition.

Other observations:

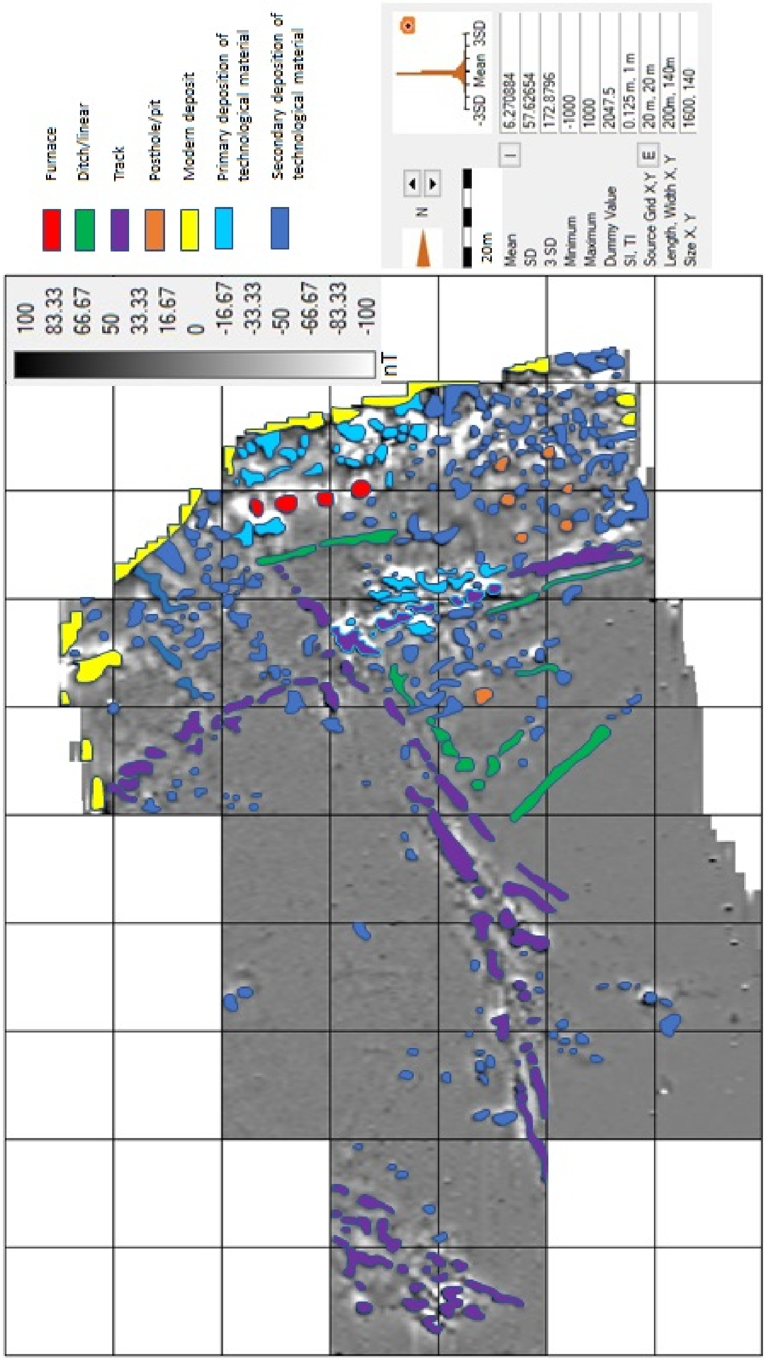

FIGURE A.37: Magnetometry Field 2 Normalised and Annotated data

Field 3

Anomalies:

Track (purple) Linear anomaly enters the field from the west and bends south at 581256E 121103N with readings up to 83nT. This is the continuation of the track seen in Field 2 labelled (B).

Modern (yellow) Area of mixed magnetic response centred on 581217E 121122N measures up to 1000nT caused by modern day interference.

Linear/ditch (green) unclear interpretation

Secondary deposition (dark blue) spread of technological waste with no clear interpretation

Other observations:

-Area of mixed magnetic response centred on 581334E 121132N measuring up to 441nT of unclear date with no obvious features.

Associations:

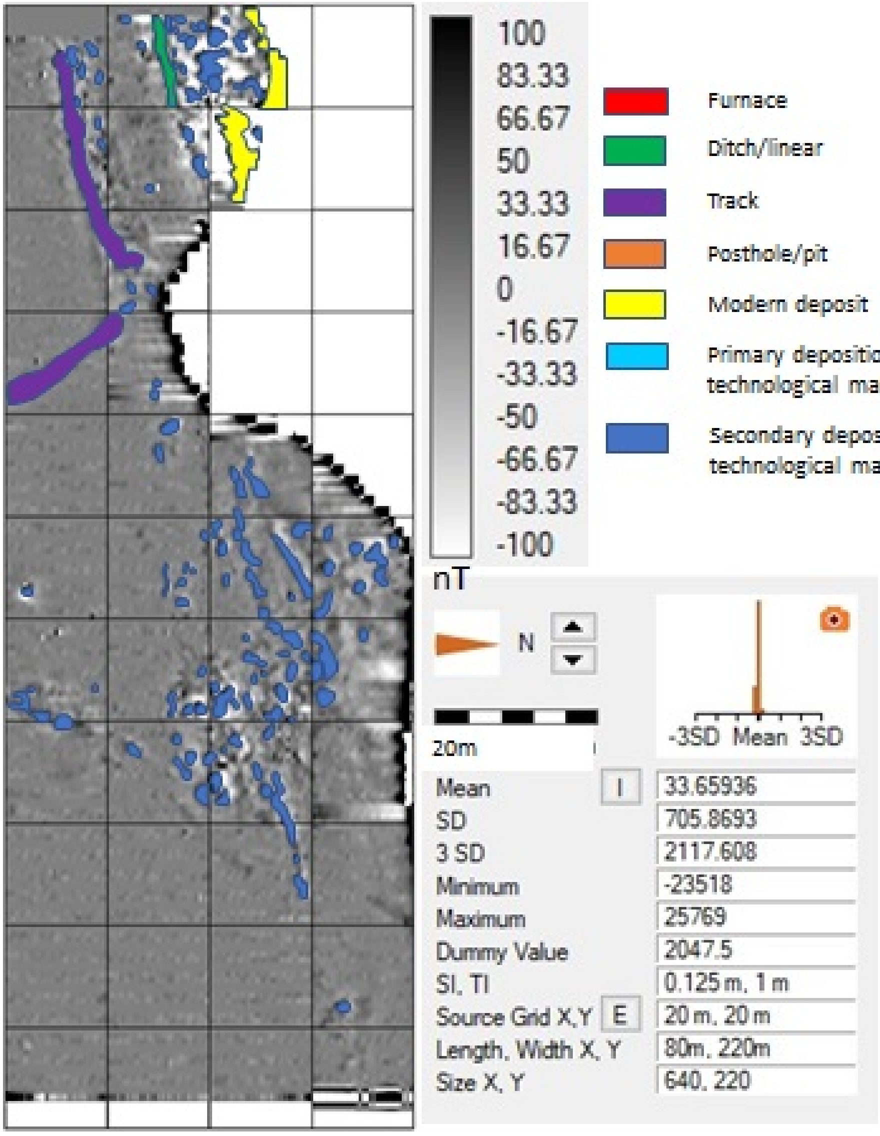

FIGURE A.38: Magnetometry Field 3 Normalised and Annotated data

A.2.2 Earth Resistivity Tomography

CH-ERT-1

Anomalies:

11-12.5m lat: UAD intrusive/infill (Green) low resistivity anomaly with lowest reading of 10 Ohms. Possible ditch or pit feature.

Other observations: Clear definition of increased resistivity near ground surface showing archaeological deposit on the natural to an average depth of about 2m.

Associations:

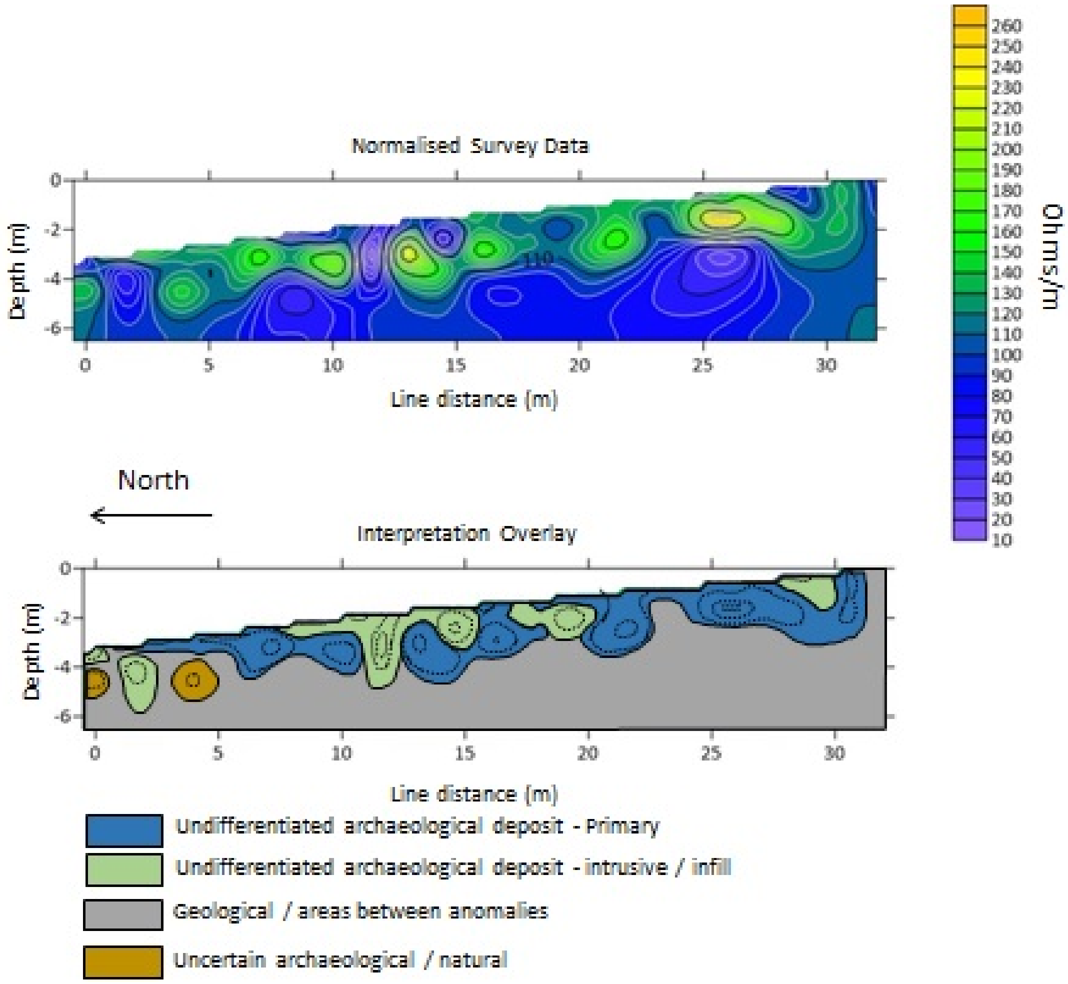

FIGURE A.39: Earth Resistivity Tomography Line 1 Normalised and Annotated data

CH-ERT-2

Anomalies:

2.5-9m lat: UAD primary (dark blue)) inverted triangle descending from the ground surface to the bottom of the survey, max depth 4m, with readings between 100-160 Ohms. unclear what this represents but believed to not be natural. Could represent a large back-filled pit or ditch feature.

15-32m lat: large area of low resistivity covering southern end of survey showing lack of archaeological deposit.

Other observations:

-Not what expected with lack of defined increased resistivity on surface with lower resistivity beneath. Anomalies mixed.

Associations:

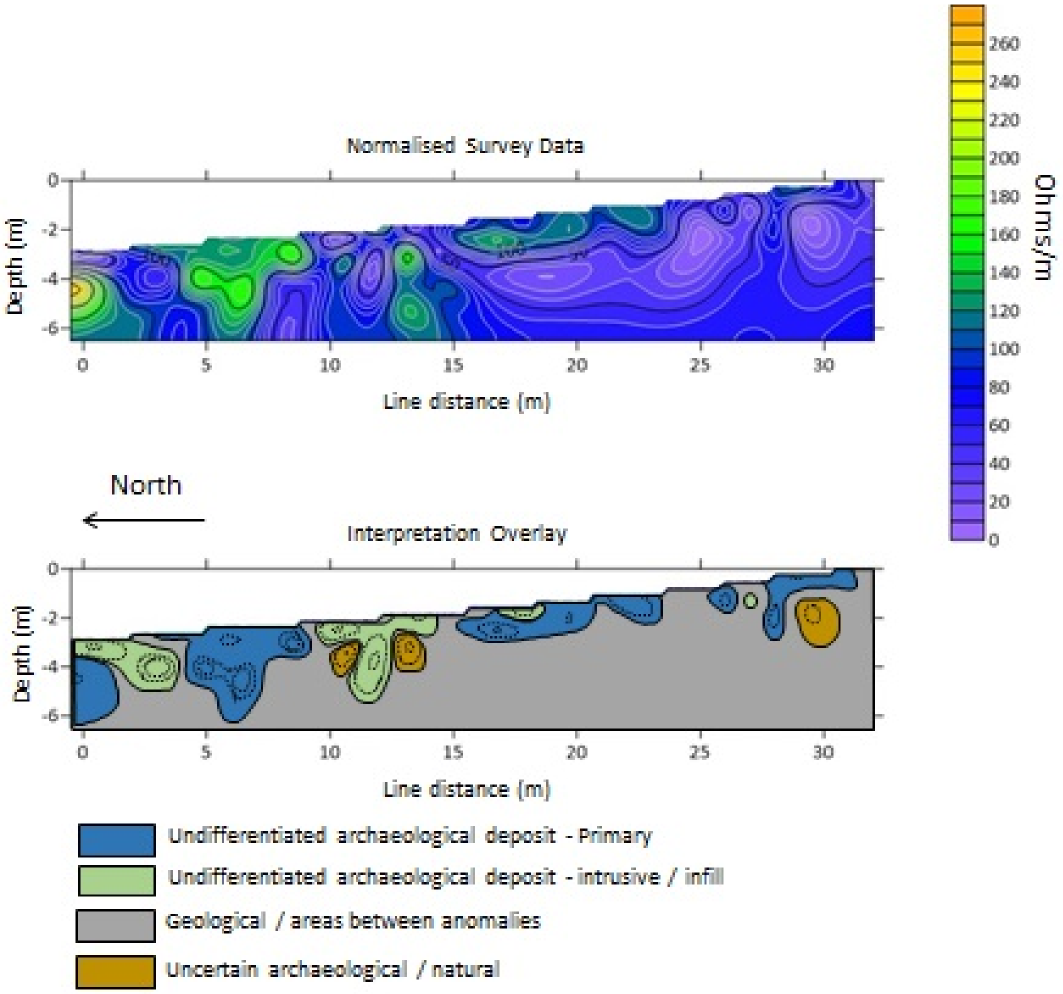

FIGURE A.40: Earth Resistivity Tomography Line 2 Normalised and Annotated data

CH-ERT-3

Anomalies:

0-2.5m lat: Modern (yellow) position of modern field gate.

10-32m lat : Variety of UADs interpreted as spread of technological waste

Other observations:

-Not what expected with lack of defined increased resistivity on surface with lower resistivity beneath. Anomalies mixed.

Associations:

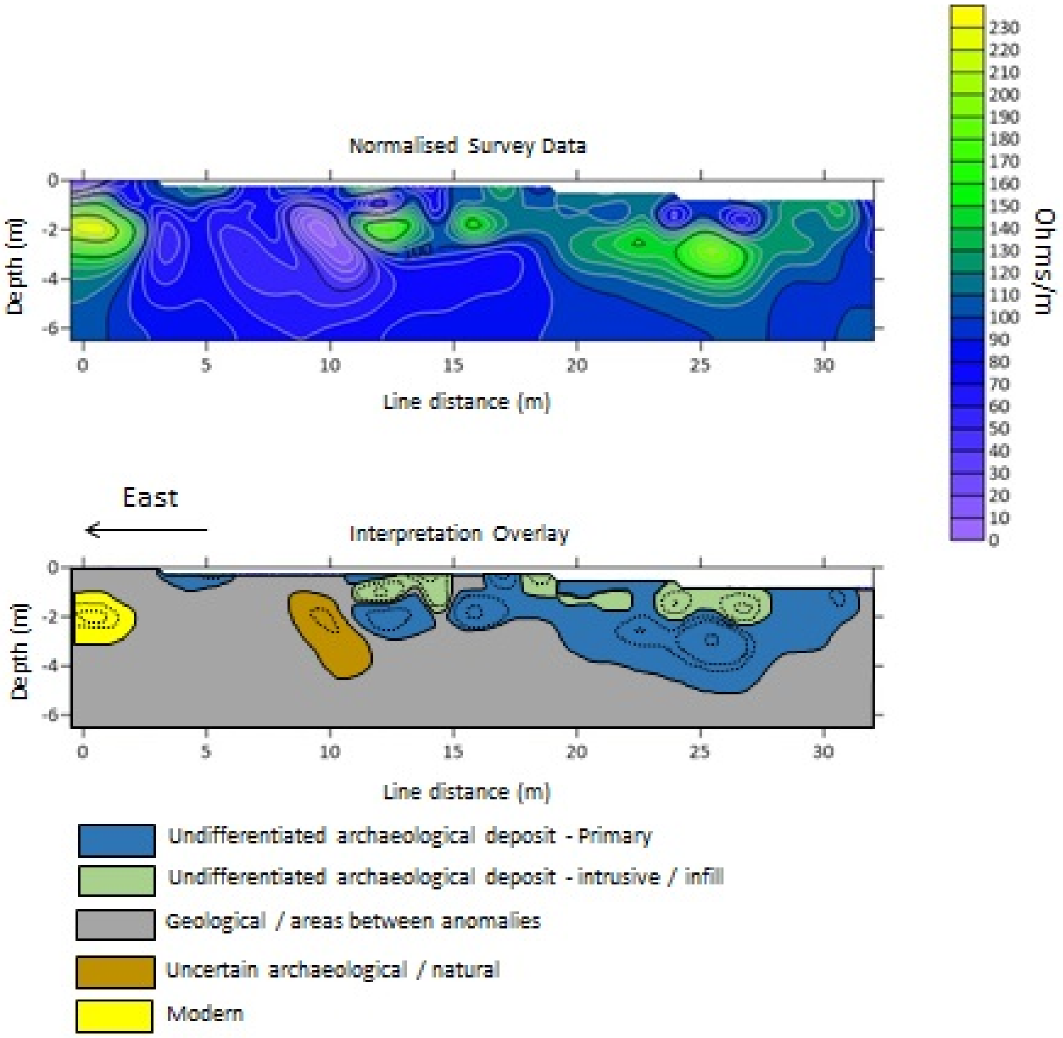

FIGURE A.41: Earth Resistivity Tomography Line 3 Normalised and Annotated data

CH-ERT-4

Anomalies:

0-4m lat: Modern (yellow) increased resistivity anomaly with readings up to 220 Ohms. In modern day gateway, therefore represents modern hardcore deposit.

54-64m lat: TWD (light blue) increased resistivity with highest reading of 150 Ohms represents the technological waste deposit as proved through excavation.

Other observations:

20-64m UADs along ground surface following a similar depth believed to represent deposits of technological waste.

Associations:

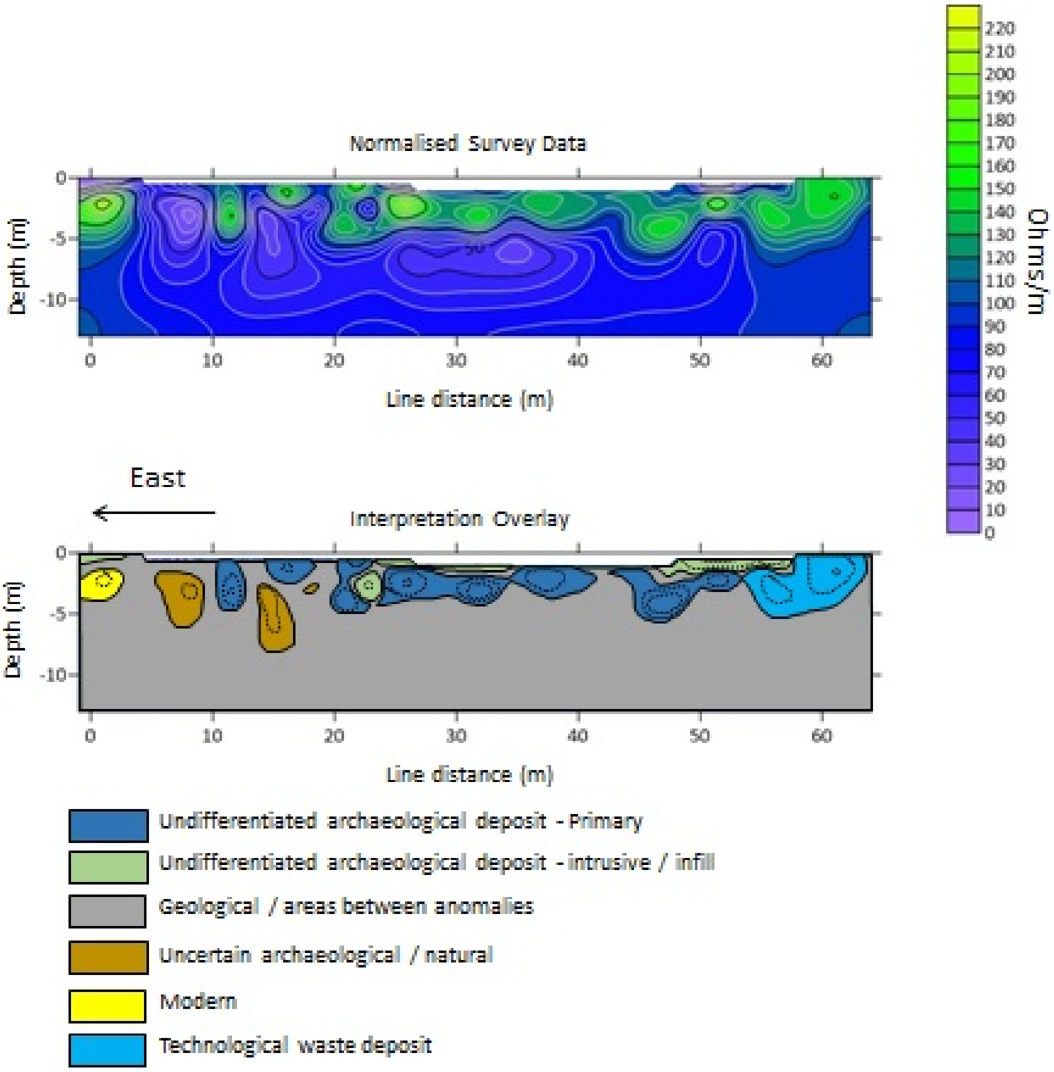

FIGURE A.42: Earth Resistivity Tomography Line 4 Normalised and Annotated data

underline**CH-ERT-5**

Anomalies:

20m lat: increased resistivity anomaly with highest reading of 160 Ohms is in the position of a magnetic anomaly believed to be a posthole.

Other observations:

Mixed UADs but overall trend is they are along the ground surface showing most likely archaeological deposit.

Associations:

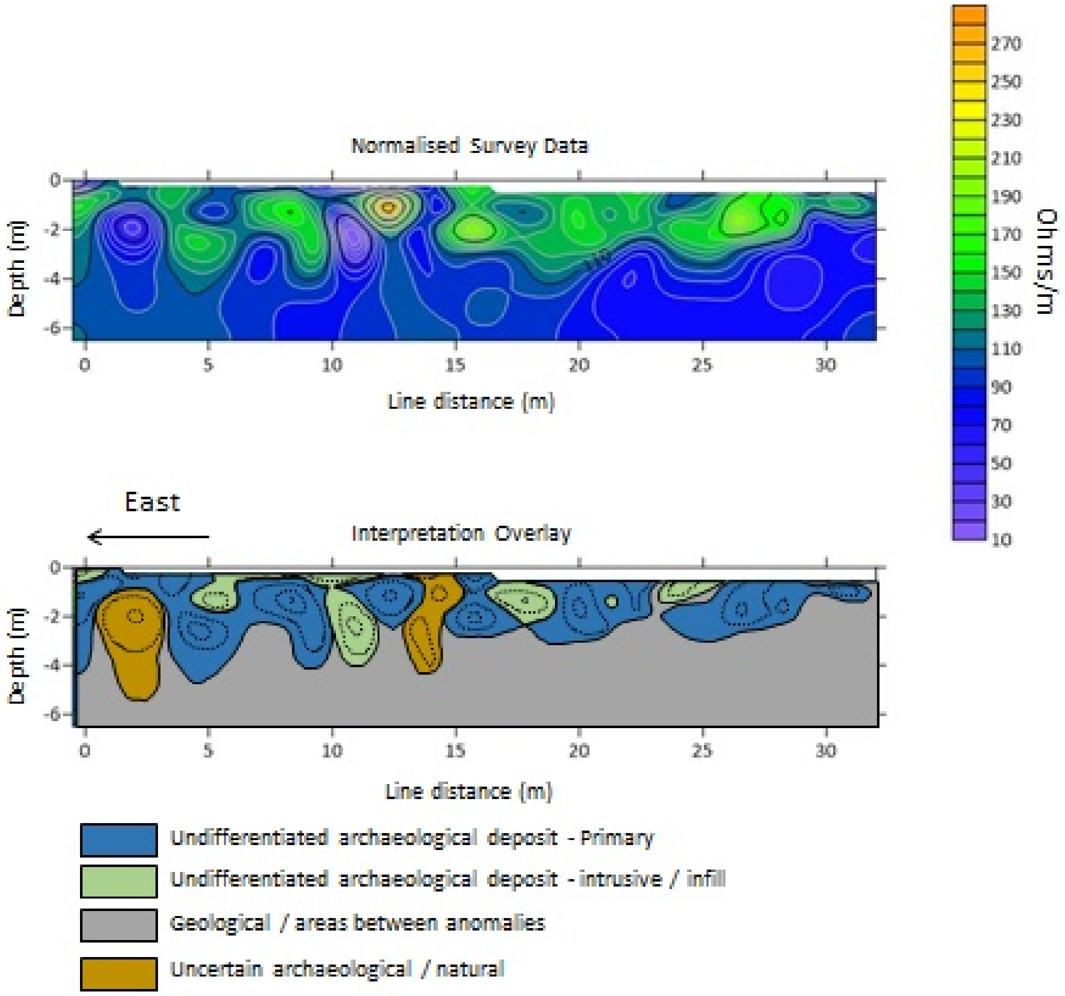

FIGURE A.43: Earth Resistivity Tomography Line 5 Normalised and Annotated data

CH-ERT-6

Anomalies:

10-16m lat: structure of low resistivity anomaly surrounded by anomalies of increased resistivity anomalies to the south and below. Low anomaly below 100 Ohms and increased anomalies above 150 Ohms. Very similar to structure of furnace.

Other observations:

-Increased resistivity to an average depth of 2m along the ground surface interpreted as archaeological deposits (UADs).

-Increased anomaly at 25m with readings of 150-170 Ohms could represent some form of foundations as it is positioned between two large postholes on mag survey.

Associations:

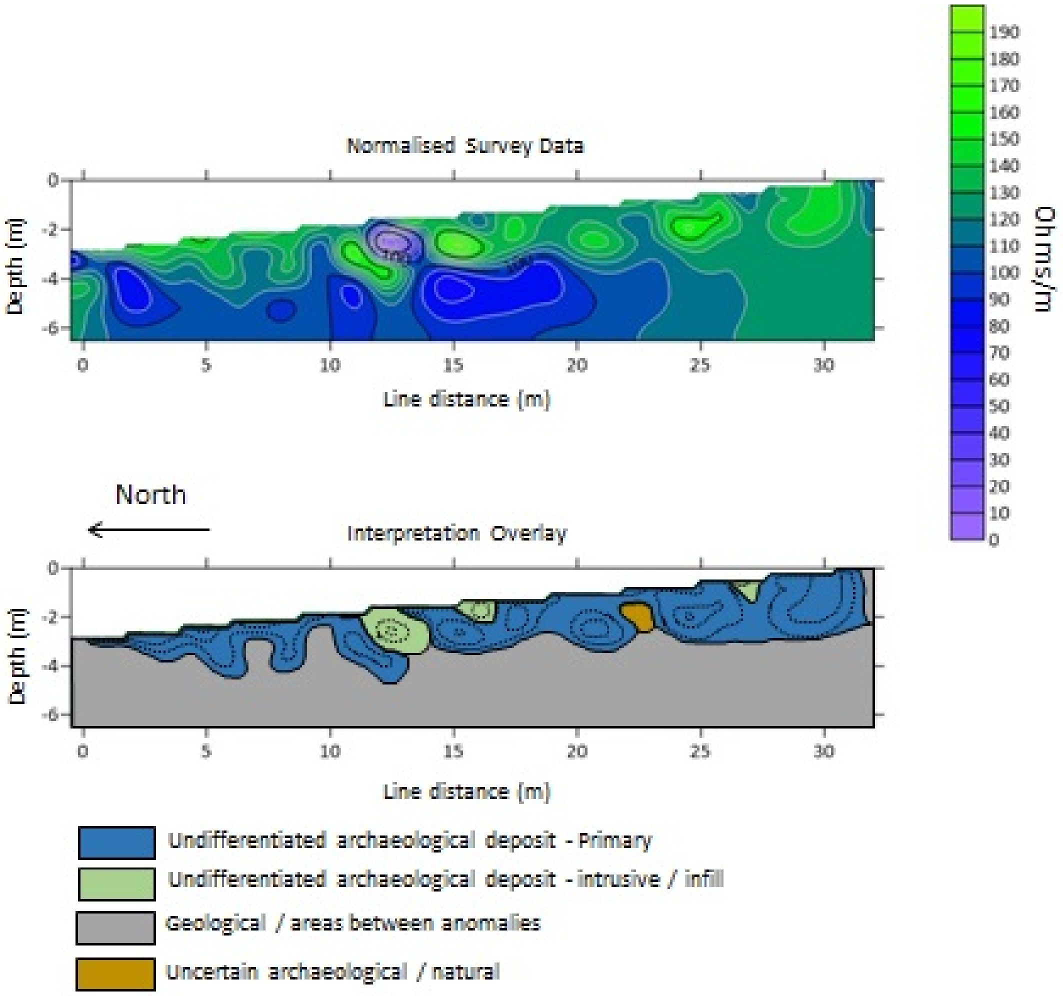

FIGURE A.44: Earth Resistivity Tomography Line 6 Normalised and Annotated data

CH-ERT-7

Anomalies:

Other observations:

-No clearly defined features in this survey line. The resistivity is mixed at a variety of depths making interpretation of archaeological or natural features near impossible.

-UAD intrusive/infill at 12.5m could represent a back filled pit or ditch feature.

Associations:

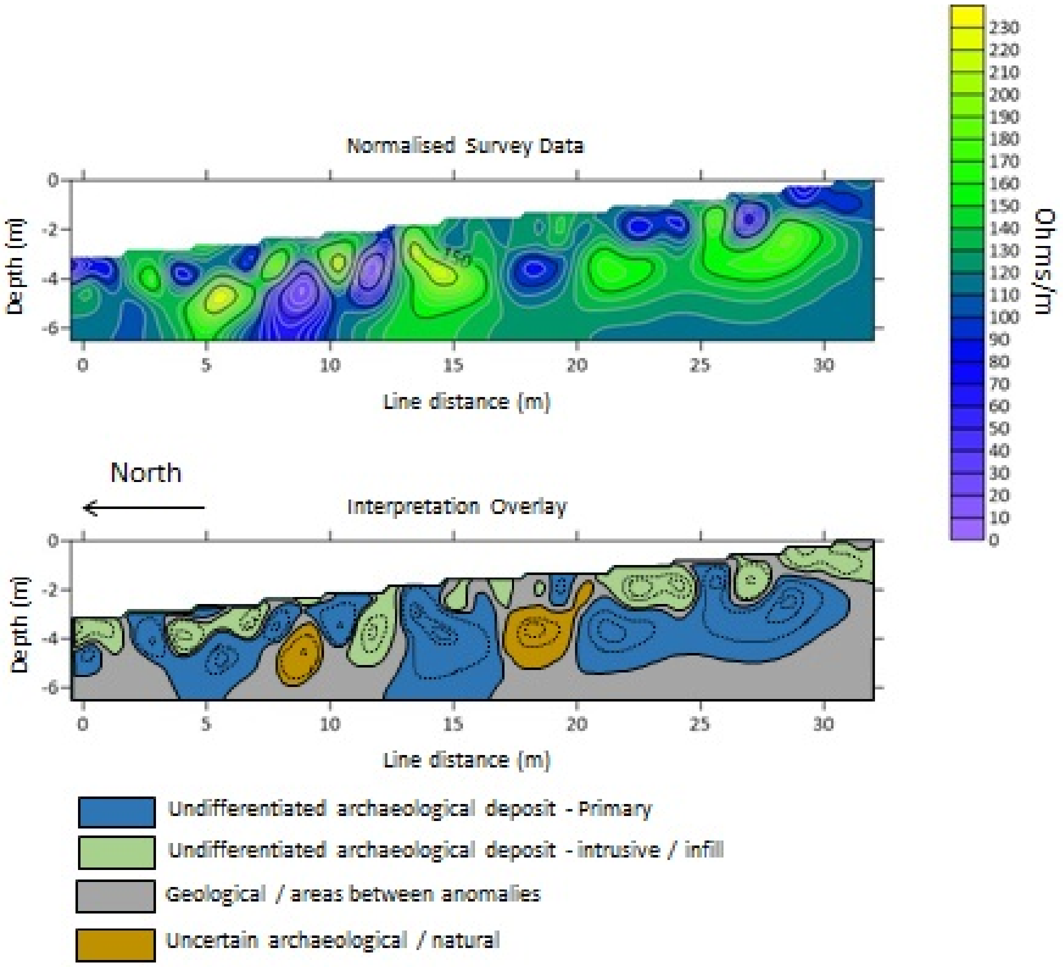

FIGURE A.45: Earth Resistivity Tomography Line 7 Normalised and Annotated data

CH-ERT-8

Anomalies:

20.5m lat: Low resistivity, UAD intrusive/infill, measuring 40 Ohms represents posthole as proved in excavations.

Other observations:

-Large increased resistivity anomalies to the south of the survey outside the smelting areas measuring up to 360 Ohms. No clear interpretation.

Associations:

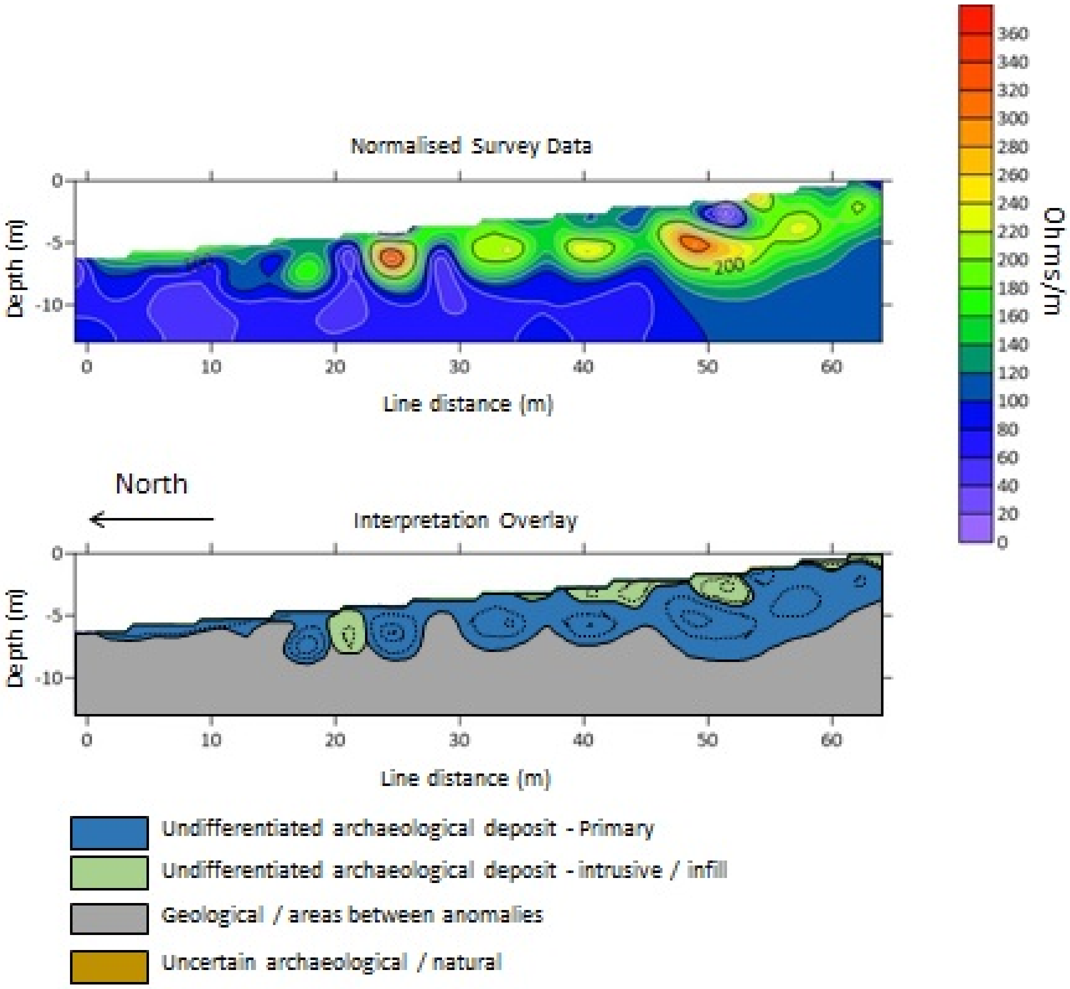

FIGURE A.46: Earth Resistivity Tomography Line 8 Normalised and Annotated data

CH-ERT-10

Anomalies:

0-7m lat: TWD (light blue) Mixed resistivity area with readings between 120-230 Ohms.

7-17m lat: Furnace (red and pink) repeat structure of low resistivity areas measuring below 50 Ohms surrounded to the south and below by areas of increased resistivity measuring between 0-190 Ohms.

25m lat: Ditch (Purple) low resistivity anomaly descending from near surface with readings below 30 Ohms.

Other observations:

-Low resistivity natural geology level to the south then descends to the north showing natural slope of ghyll side.

-In smelting workshop general spread of material with possible pit or ditch feature at 22m.

Associations:

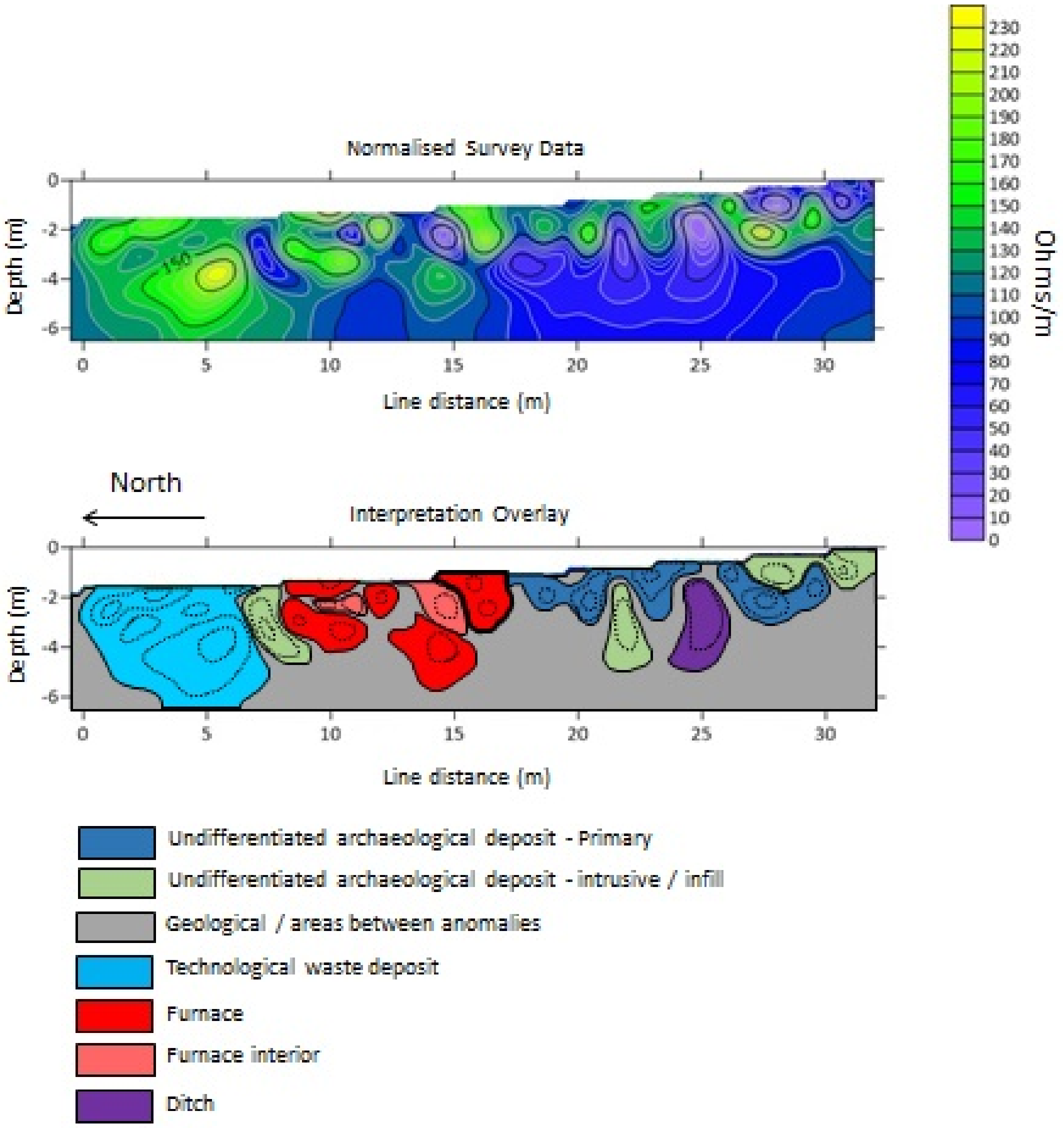

FIGURE A.47: Earth Resistivity Tomography Line 10 Normalised and Annotated data

CH-ERT-11

Anomalies:

0-6m lat: TWD (light blue) Mixed resistivity area with readings between 160-250 Ohms.

19-20m lat: anomaly with readings between 160 to 250 with highest resistivity at its base. Possible post hole with packing.

25m lat: Ditch (purple) low resistivity anomaly descending from near surface with readings below 60 Ohms.

Other observations:

-Most anomalies within 2m of the ground surface with the lower resistivity natural below 2m.

Associations:

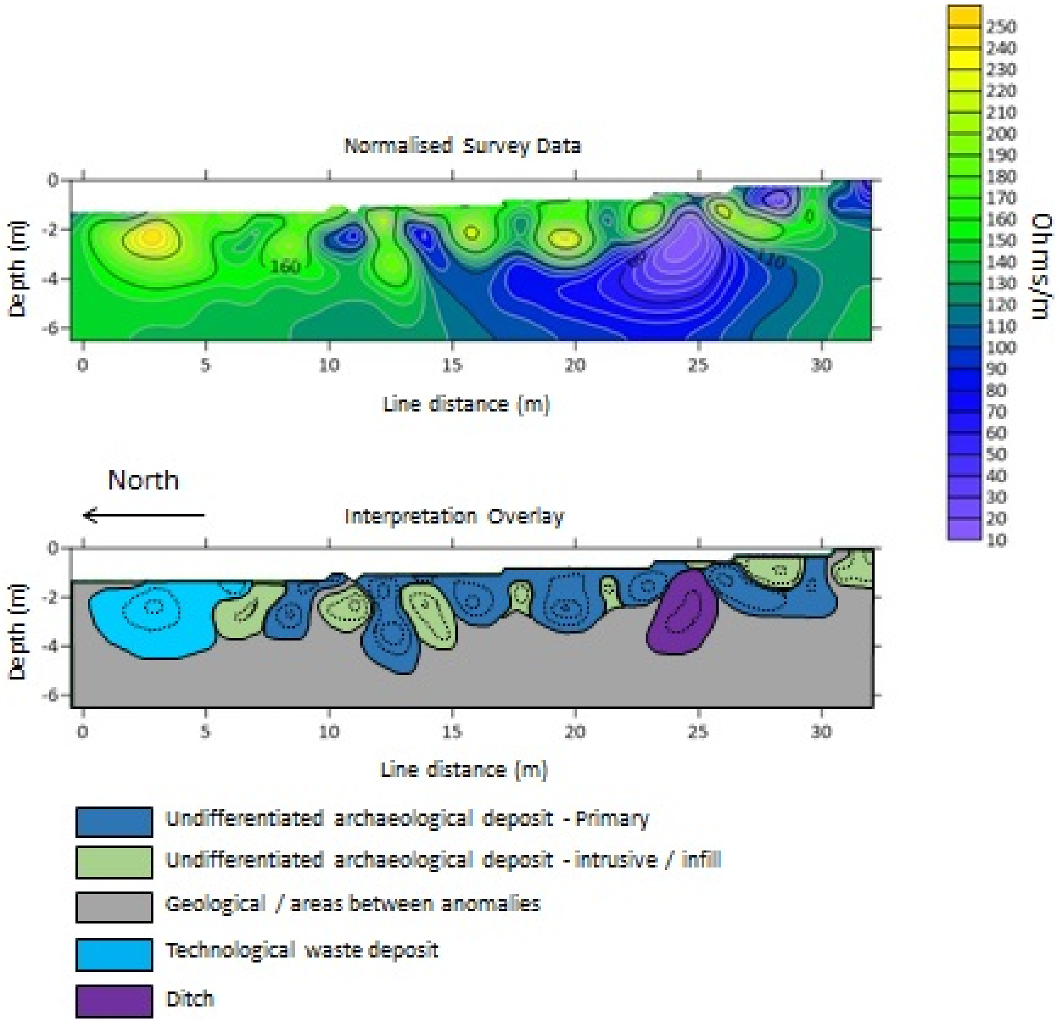

FIGURE A.48: Earth Resistivity Tomography Line 11 Normalised and Annotated data

CH-ERT-12

Anomalies:

0-7m lat: TWD (light blue) Mixed resistivity area with readings between 180-250 Ohms.

25m lat: Ditch (purple) low resistivity anomaly descending from near surface with readings below 100 Ohms.

Other observations:

-Area in the smelting workshop show undefined deposits in the top 3m of the ground. There are no clearly defined features and increased resistivity representing technological waste.

Associations:

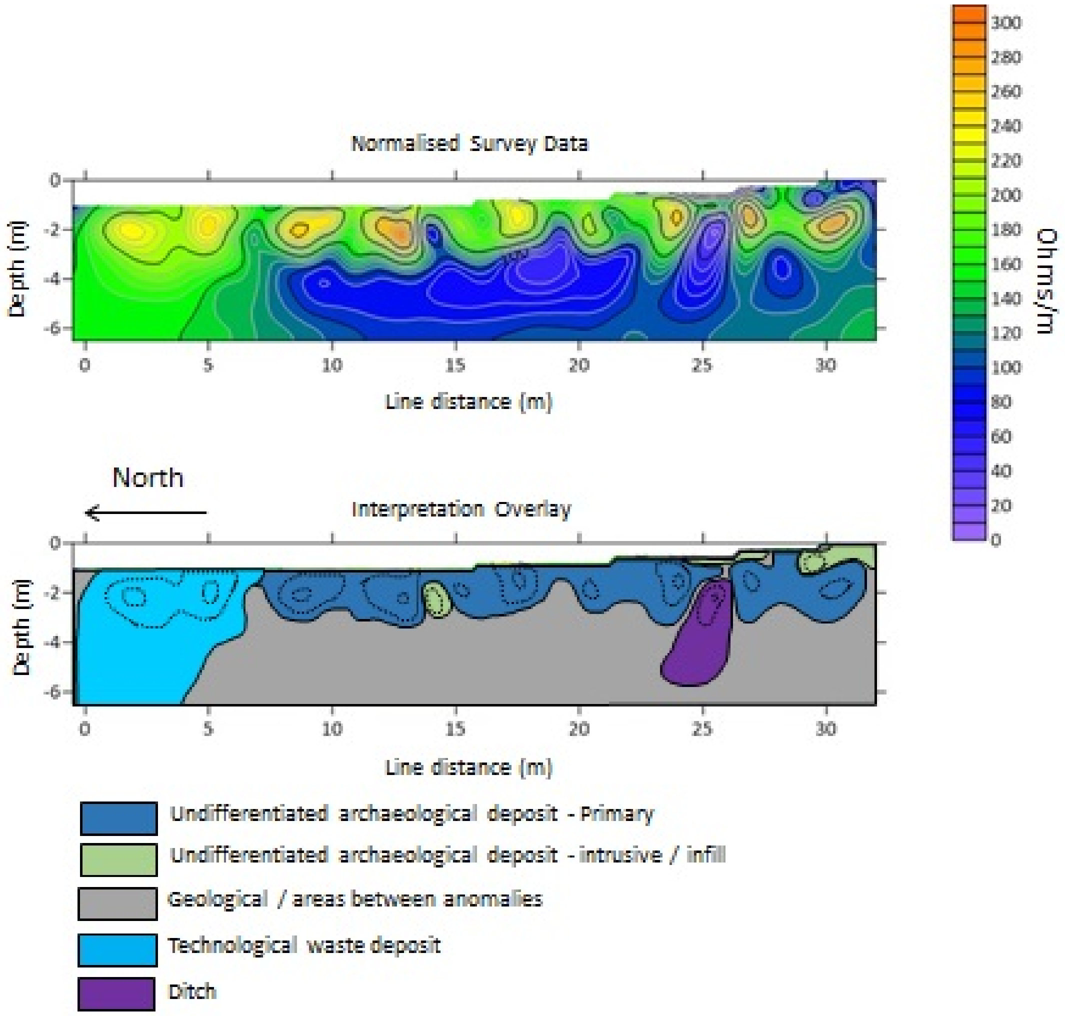

FIGURE A.49: Earth Resistivity Tomography Line 12 Normalised and Annotated data

CH-ERT-13

Anomalies:

0-7m lat: TWD (light blue) Mixed resistivity area with readings between 180-290 Ohms.

22.5m lat: Ditch (purple) low resistivity anomaly descending from near surface with readings below 80 Ohms.

Other observations:

-12.5m lat anomaly of increased resistivity with decreased resistivity to its south. This is positioned on the edge of a furnace and could represent part of its structure but not clear.

-Across the smelting workshop increased resistivity anomalies which are believed to be caused by technological waste shows depth of archaeological deposit within 3m of the ground surface.

-Natural geology runs under smelting workshop with lower resistivity which increases under waste deposit. Could be down to the way data collected, less reliable in lower corners.

Associations:

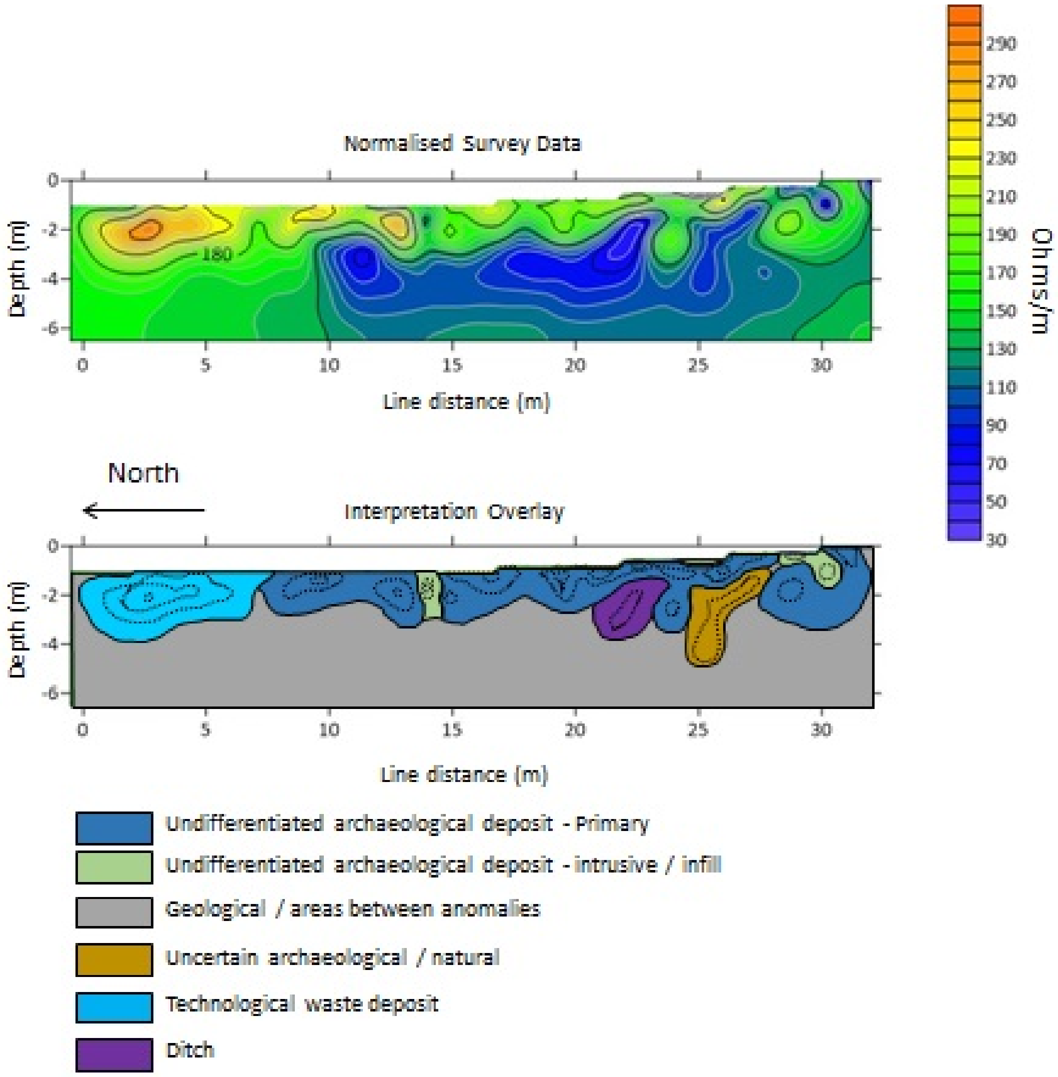

FIGURE A.50: Earth Resistivity Tomography Line 13 Normalised and Annotated data

A.2.3 Induced Polarisation

CH-IP-1

Anomalies:

7.5-15m lat: Three anomalies along the ground surface in an 'M' shape, with readings between 200-340 are in the area of known Victorian land-drains.

Other observations:

-The rest of the survey is lower polarisation with a number of anomalies with no clear interpretation. These anomalies are within the top 2m of the ground surface so could be interpreted as being archaeological.

Associations:

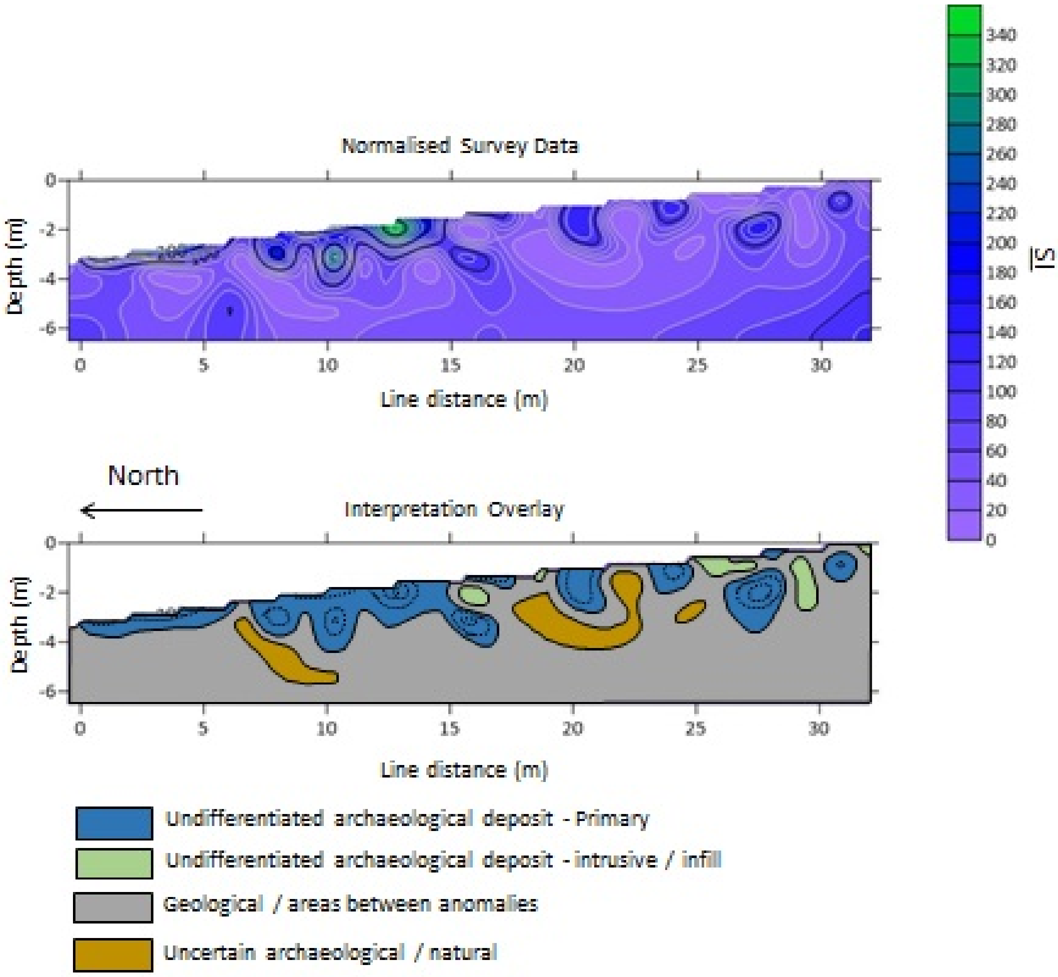

FIGURE A.51: Induced Polarisation Line 1 Normalised and Annotated Data

CH-IP-2

Anomalies:

0-10m lat: UAD (dark blue)Increased anomaly along the ground surface with readings up to 650. Unclear interpretation between archaeological or modern.

15-20m lat: UAD (dark blue) Increased anomaly with readings up to 900. The form and positioning of this anomaly matches one in the ERT survey for this line indicating a possible pit like feature which has been back-filled with a highly polarising material.

Other observations:

Associations:

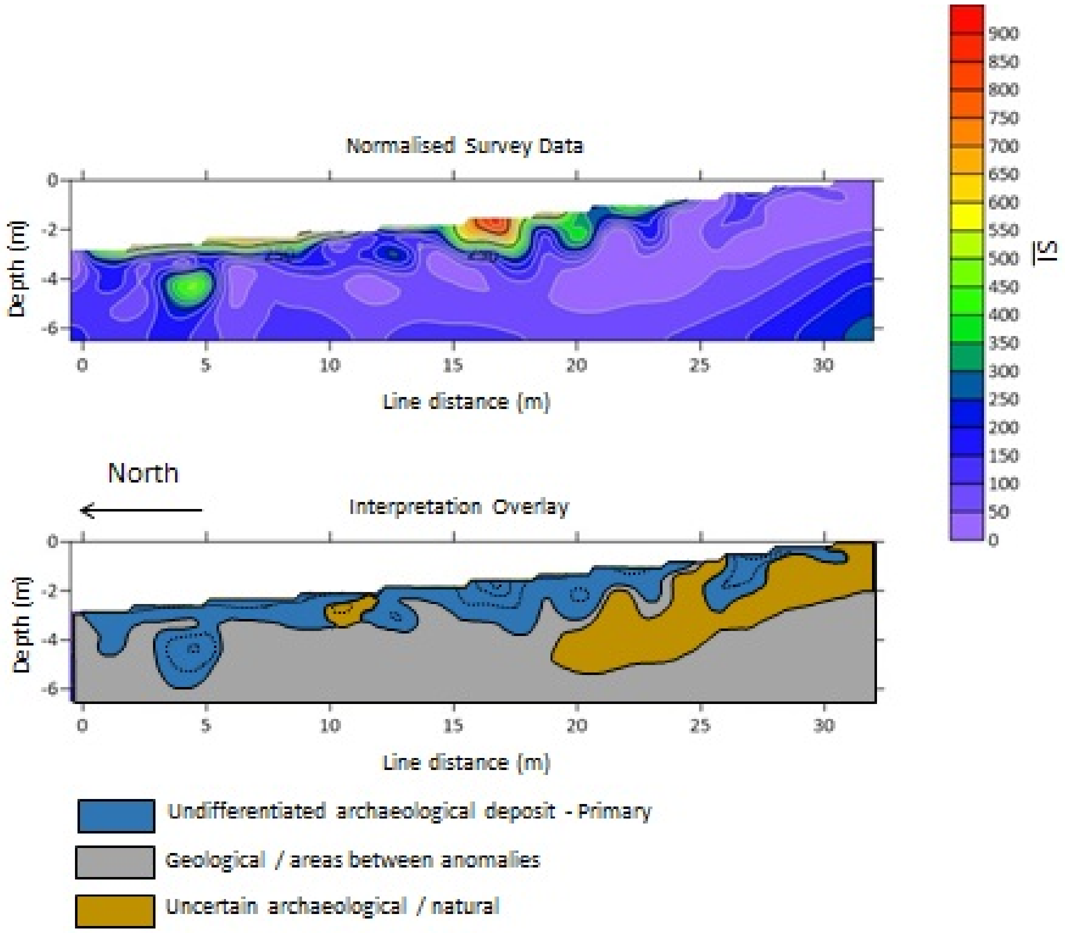

FIGURE A.52: Induced Polarisation Line 2 Normalised and Annotated Data

CH-IP-3

Anomalies:

0-2m lat: Modern (yellow) High polarisation anomaly with readings up to 2300. This is in the gateway between the two field and therefore represents a modern deposit of hardcore material for the gates construction.

24-27.5m lat: UAD (dark blue) ′n′ shaped anomaly with readings up to 200. This is in the position of known Victorian land-drains and matches in position with anomalies in the ERT survey.

Other observations:

-Spread of increased polarisation within 2m of the ground surface across much of the survey which can be interpreted as possible archaeological material.

Associations:

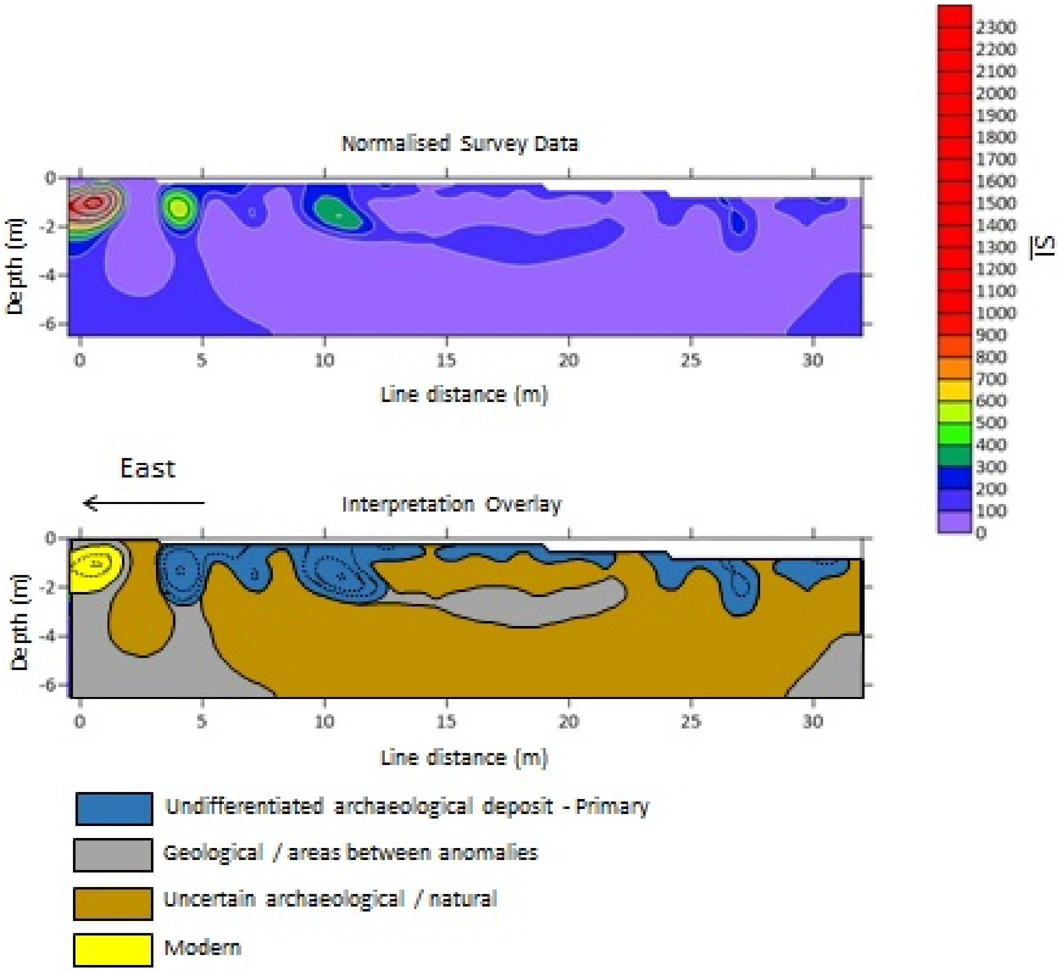

FIGURE A.53: Induced Polarisation Line 3 Normalised and Annotated Data

CH-IP-4

Anomalies:

0-4m lat: Modern (yellow) High polarisation anomaly with readings up to 850. This is in the gateway between the two fields.

58-62m lat: TWD (light blue) High polarisation anomaly with reading up to 850.

Other observations:

-A number of anomalies along the near surface that are interpreted as archaeological deposits with no clear interpretations.

Associations:

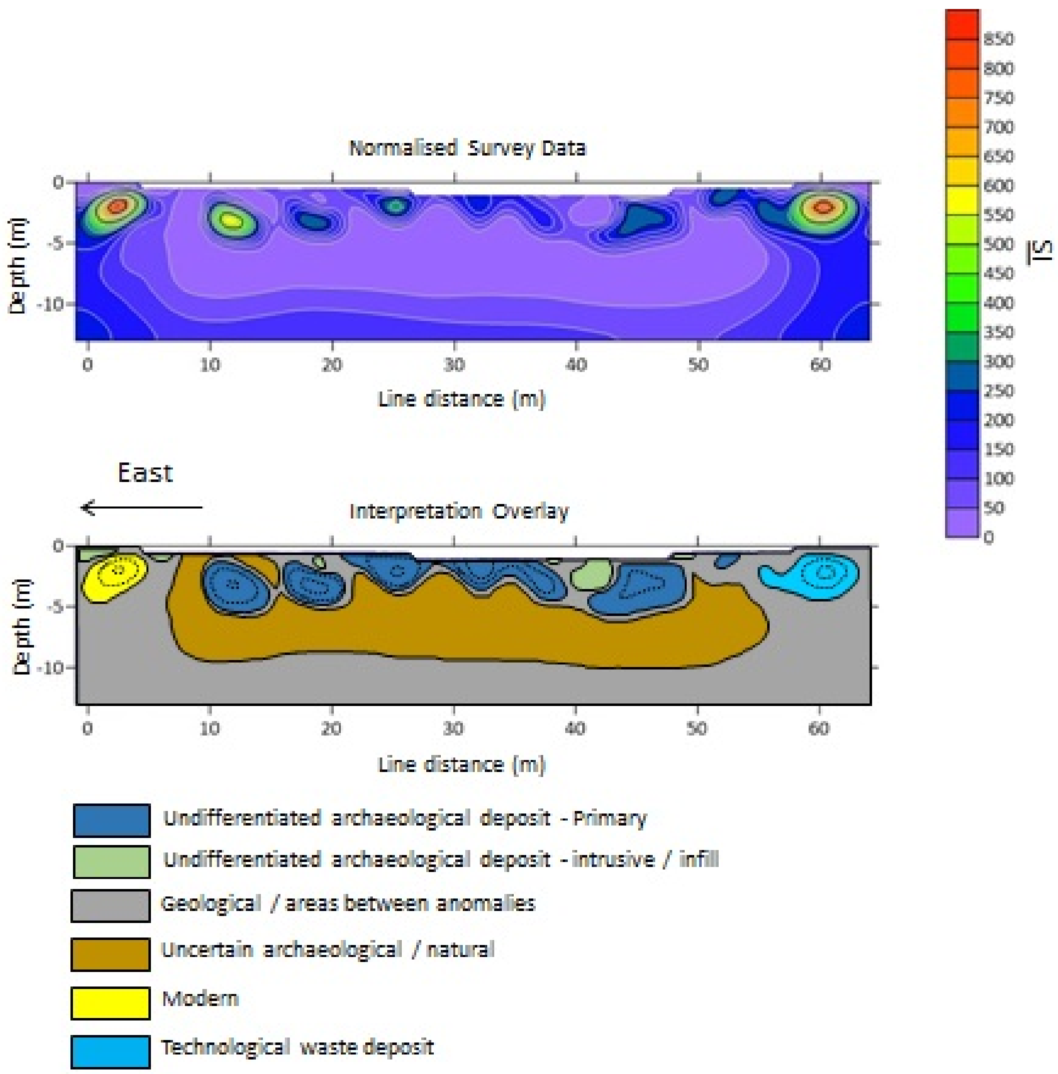

FIGURE A.54: Induced Polarisation Line 4 Normalised and Annotated Data

<u>**CH-IP-5**</u>

Anomalies:

20m lat: UAD (dark blue) Small anomaly with a reading of 220 interpreted as a post-hole form magnetometer survey.

Other observations:

-A number of anomalies along the near surface that are interpreted as archaeological deposits with no clear interpretation.

Associations:

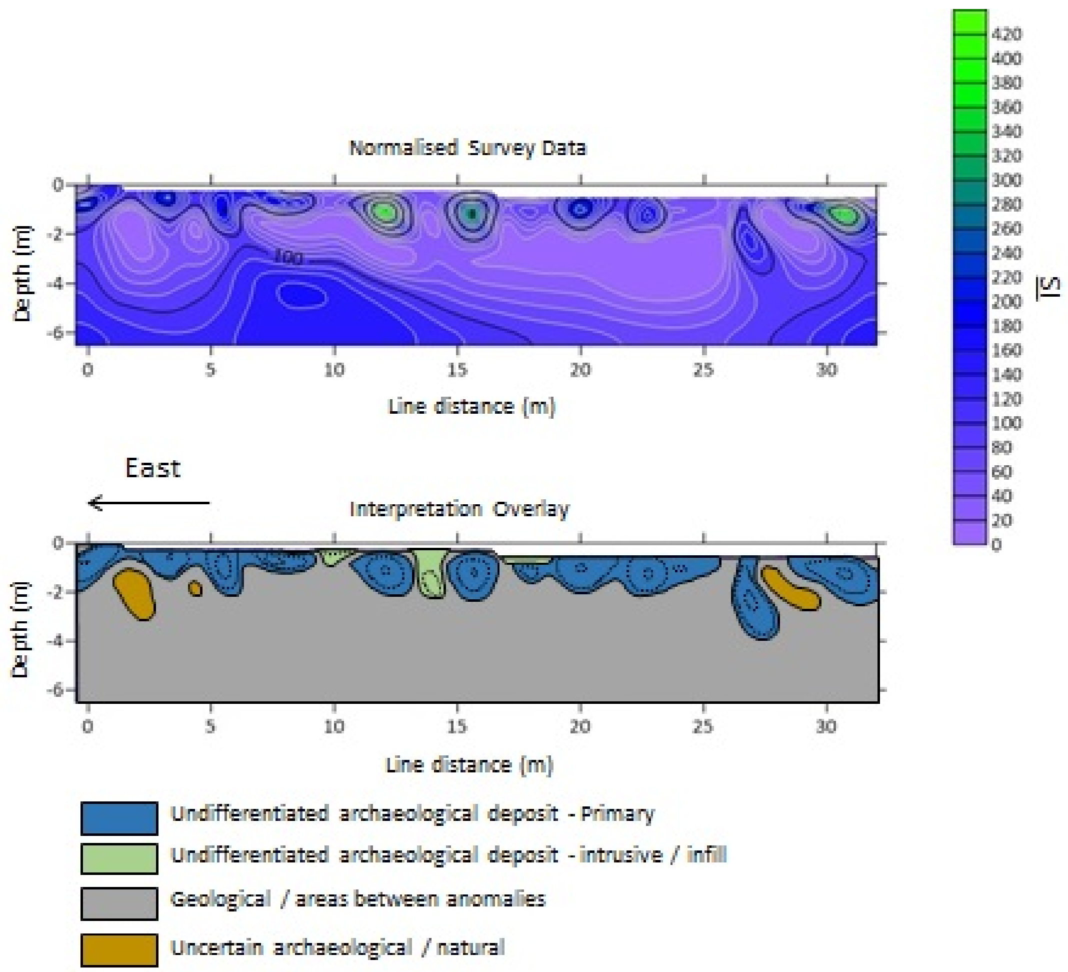

FIGURE A.55: Induced Polarisation Line 5 Normalised and Annotated Data

CH-IP-6

Anomalies:

25-32m lat: Two increased polarisation anomalies with readings up to 320 either side of an area with polarisation of 0. This lines up with the trackway in the magnetometer survey with the increased polarisation anomalies likely to represent ditches running along the edge of the track.

Other observations:

-Increased anomaly at 10m lines up with an anomaly in the res survey which looked similar to the smelting furnaces. However this anomaly lacks enough form or similarity for comparison.

-A number of anomalies sit along the near surface and likely represent archaeological deposits.

Associations:

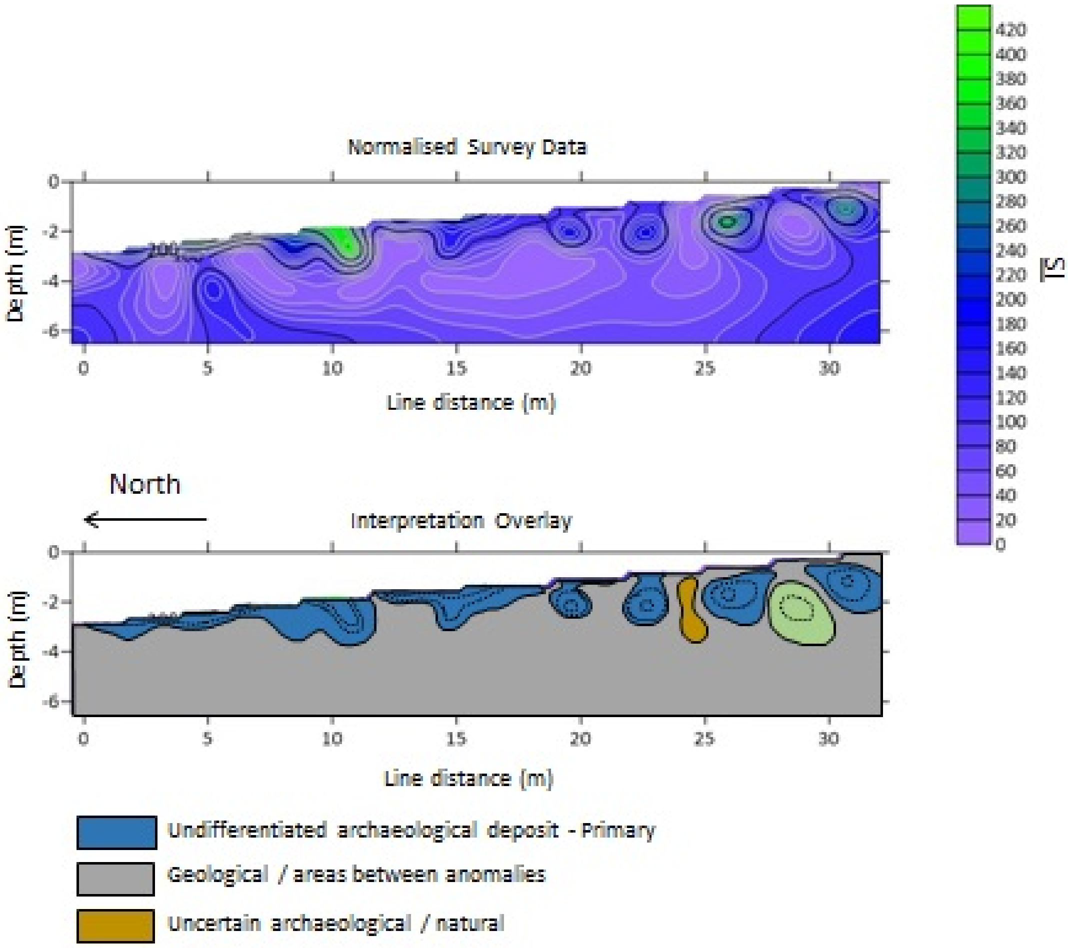

FIGURE A.56: Induced Polarisation Line 6 Normalised and Annotated Data

CH-IP-7

Anomalies:

Other observations:

-This survey line contains no interpretative anomalies except they follow the trend of being along the near surface allowing a general interpretation of archaeological deposit.

Associations:

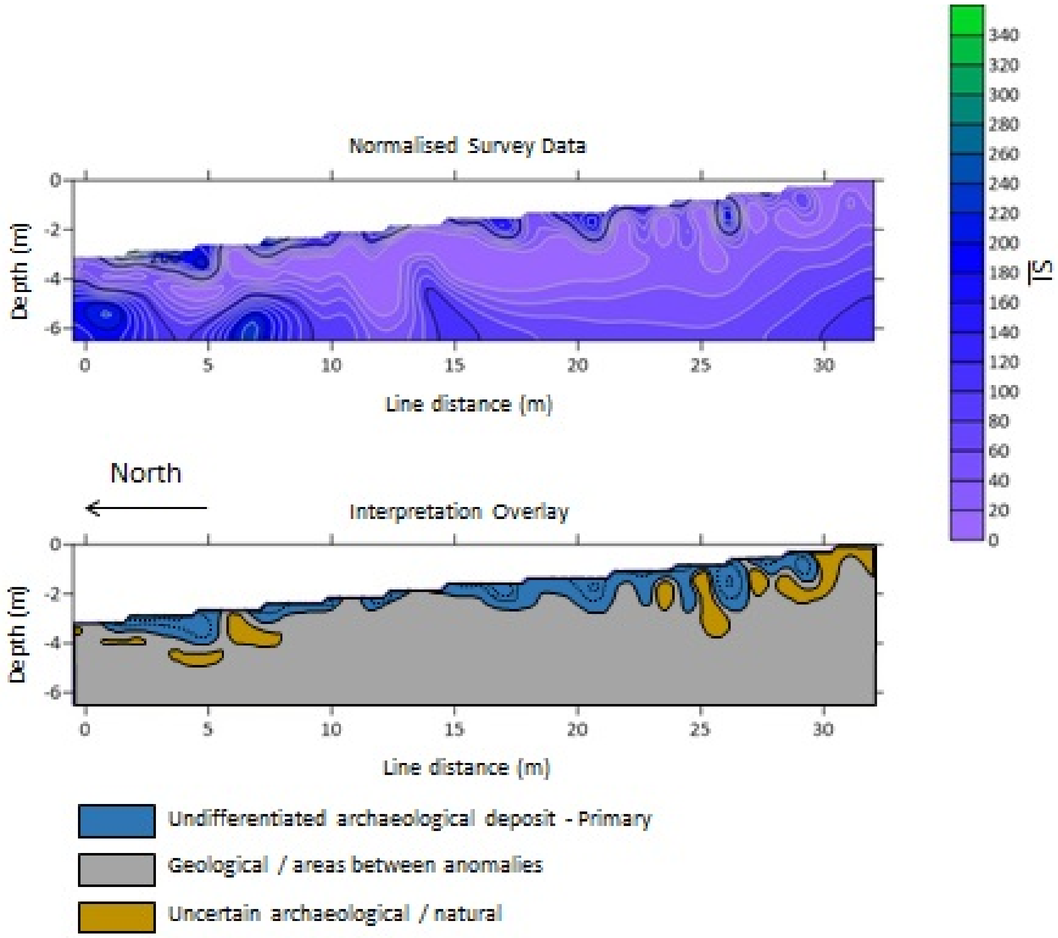

FIGURE A.57: Induced Polarisation Line 7 Normalised and Annotated Data

CH-IP-8

Anomalies:

-extremely high anomaly at 10m to 20m interpreted at UAD as upper edge in zone of possible archaeology.

Other observations:

Associations:

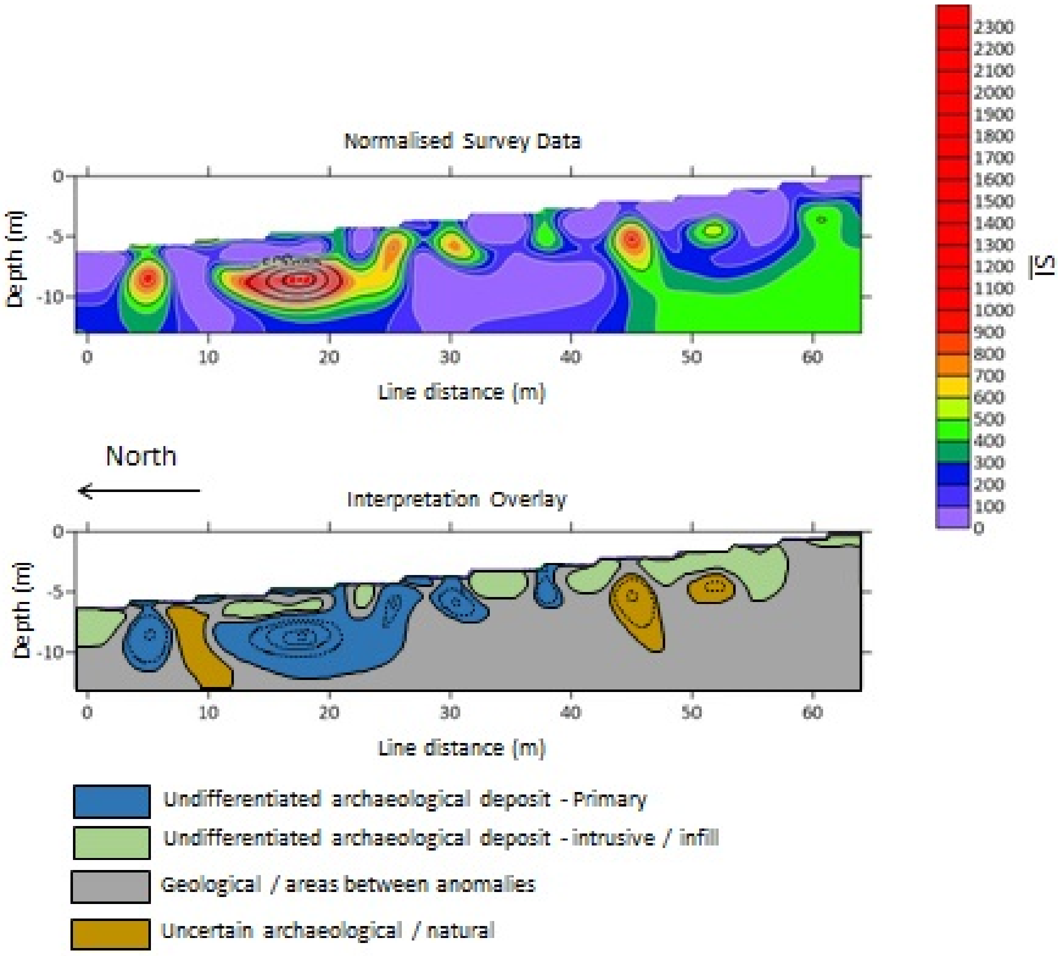

FIGURE A.58: Induced Polarisation Line 8 Normalised and Annotated Data

CH-IP-10

Anomalies:

0-6m lat: TWD (light blue) Area of mixed low polarisation anomalies, reading between below 100.

14-17.5m lat: 'C' shaped anomaly of polarisation of between 80-200 with lower polarisation at its centre of 0. This is in the position of the smelting furnace in the magnetometer and ERT survey. Could show the structure with lower polarisation response from the internal material.

18-20m lat: Anomaly penetrating down from ground surface with a general reading of above 80, with a highest point at its base of 260. Represents possible posthole.

Other observations:

-Area at depth believed to represent geology shows lower polarisation with larger area measuring 0. At 3-7.5m there is a large anomaly measuring 420 which is believed to represent a change in the natural geology.

Associations:

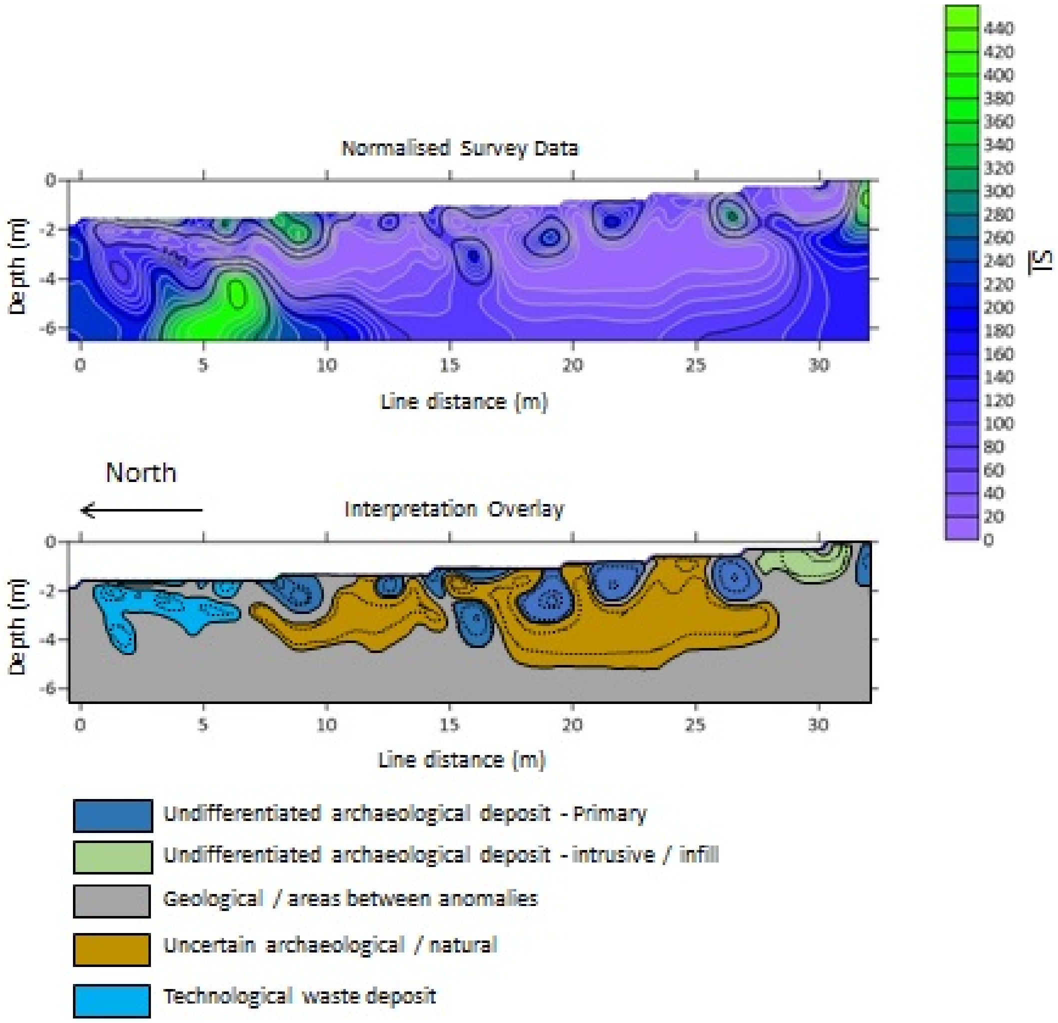

FIGURE A.59: Induced Polarisation Line 10 Normalised and Annotated Data

<u>CH-IP-11</u>

Anomalies:

0-6m lat: TWD (light blue) Area of mixed polarisation with readings from 0 to 550.

(B) 25m lat: Ditch (purple) Low polarisation anomaly with reading 0 between two anomalies of increased polarisation. The northern having readings up to 600 the southern having readings up to 1100.

Other observations:

-Survey dominated by low polarisation with readings of below 100, but predominantly below 50, believed to represent the response to the natural clay geology.

Associations:

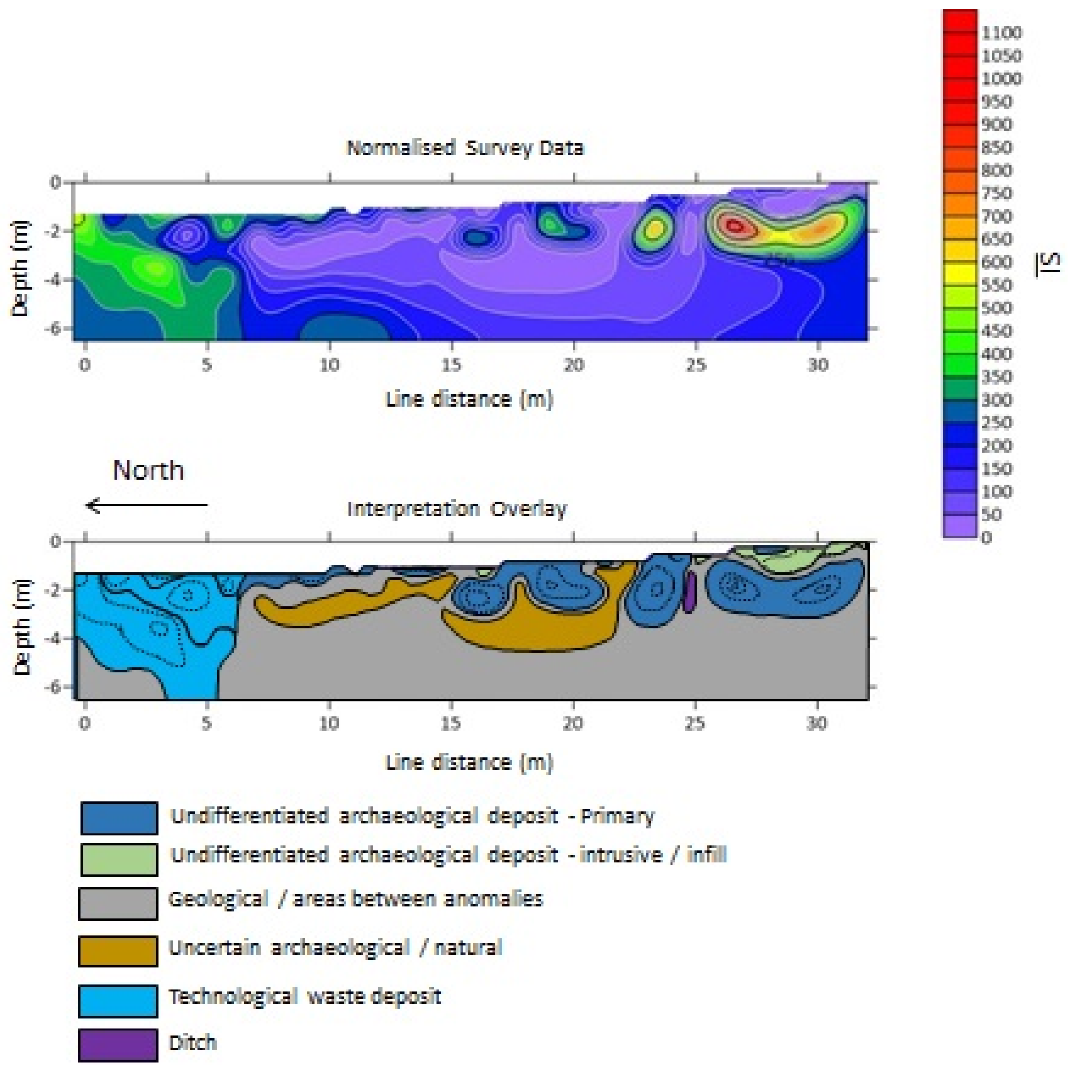

FIGURE A.60: Induced Polarisation Line 11 Normalised and Annotated Data

<u>CH-IP-12</u>

Anomalies:

0m lat: TWD (light blue) Increased polarisation anomaly in the area of the technological waste deposit with readings up to 950.

1-5m lat: TWD (light blue) Area of mixed lower polarisation anomalies within the area of the technological waste deposit measuring below 200..

(C) 25m lat: Ditch (purple) low polarisation anomaly possibly including increased anomaly to the north.

Other observations:

-There are a number of mix polarisation anomalies at the near ground surface which could be interpreted as deposits relating to the smelting process.

-Large areas of the survey measure between 0-100 SI and is interpreted as the response from the natural clay geology.

Associations:

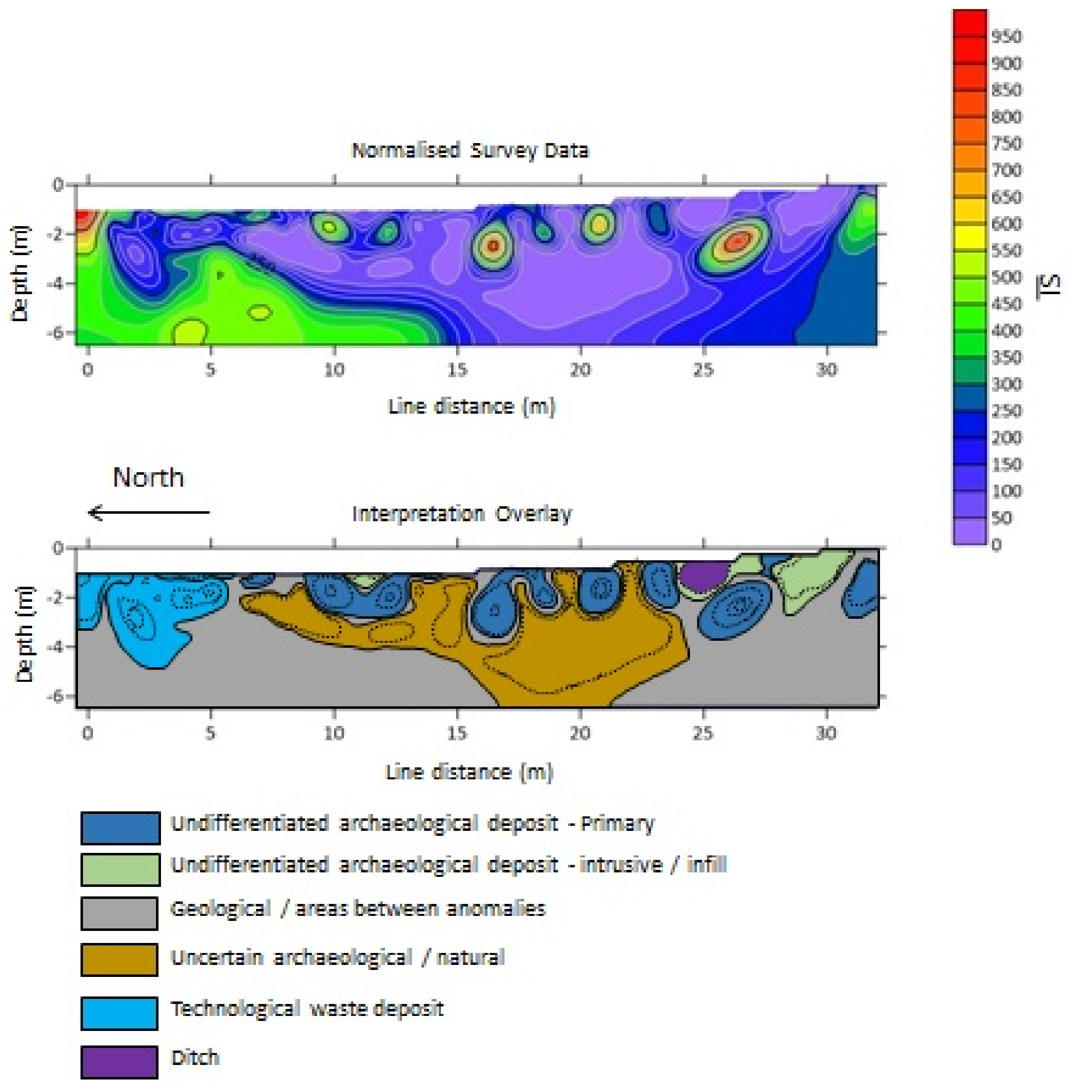

FIGURE A.61: Induced Polarisation Line 12 Normalised and Annotated Data

CH-IP-13

Anomalies:

(A) 0-6m lat: TWD (light blue) Area of mixed polarisation with readings between 0-850.

(B) 16.5m lat: Anomaly with a reading between 250-300 in the position of a large magnetic anomaly in the magnetometer survey. Could show the structure of this feature being ditch like.

Other observations:

-Large ditch like anomaly with low polarisation at 25m could represent the ditch around the smelting workshop but unclear interpretation.

Associations:

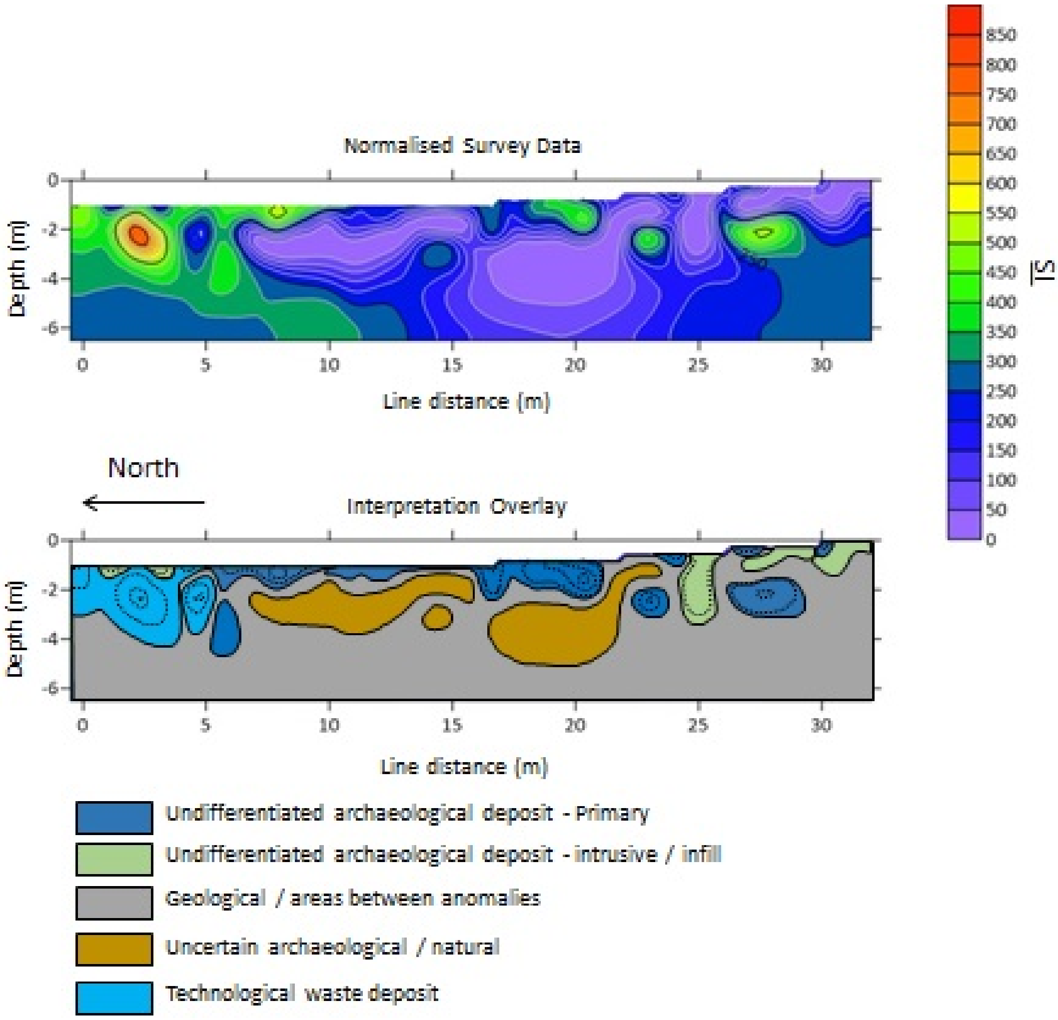

FIGURE A.62: Induced Polarisation Line 13 Normalised and Annotated Data

A.2.4 Electromagnetic

In-phase

CHF1-IN-15K

Anomalies:

(A) 581022E,121064N: Increased mag sus anomaly with reading up to 16500ppm. In the same position as the smelting furnace, this is therefore its interpretation.

(B) 581027E,121055N: Anomaly with reading up to 12000ppm biased towards the eastern side of the survey. Interpreted as response from smelting workshop ditch.

(C) 581030E,121047N: Anomaly formed of two points of increased mag sus. One measuring up to 13500ppm, the other up to 16000ppm. Interpreted as the response from a possible working area associated with iron production.

Other observations:

-Areas around the anomalies have readings between 6500-9000ppm. This could be indicitive of the response to the natural geology.

Associations:

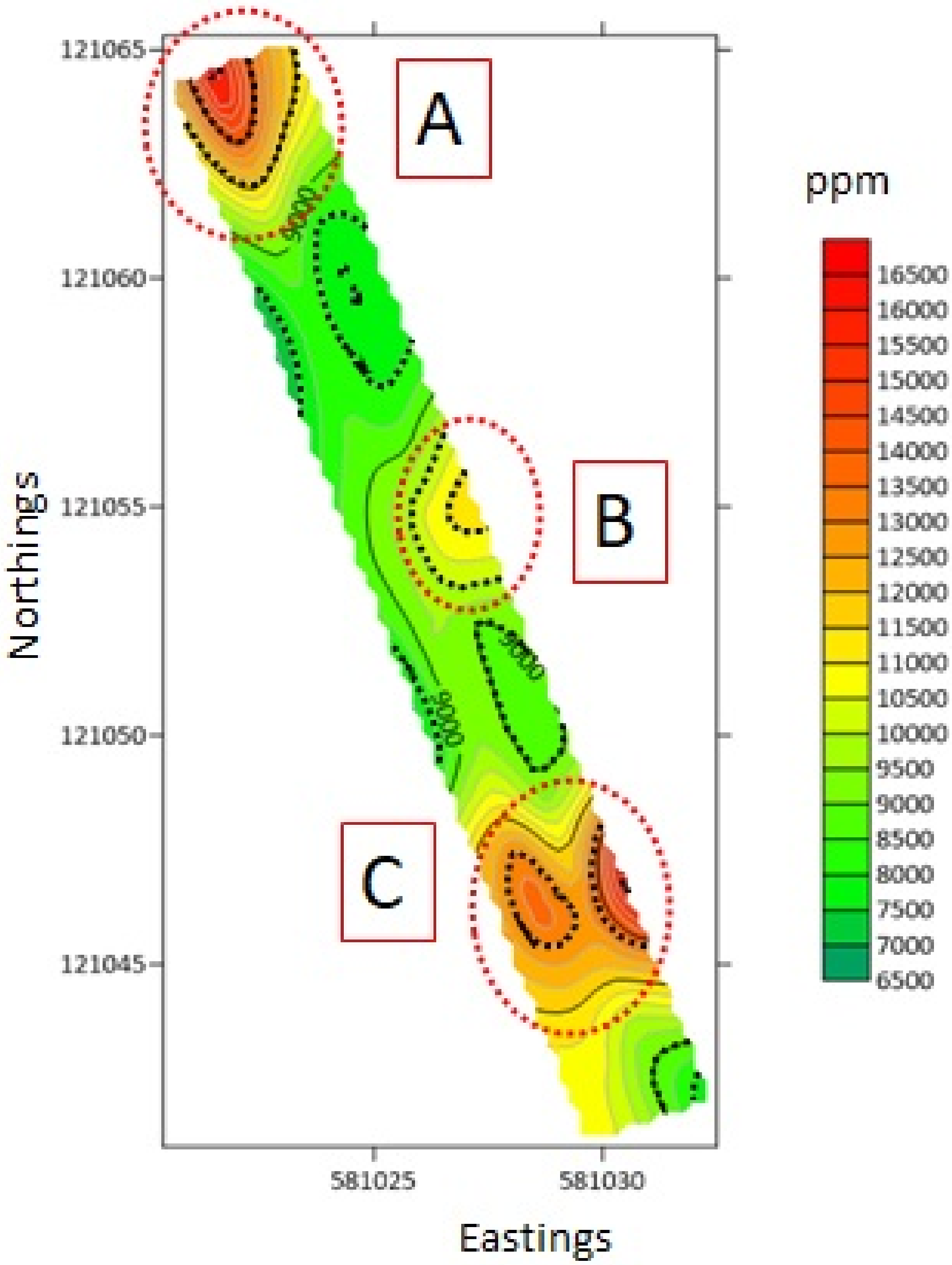

FIGURE A.63: In-phase 15kHz Field 1 Normalised and Annotated

Line CHF1-IN-3K

Anomalies:

(A) 581022E,121064N: Increased mag sus anomaly with reading up to 13500ppm. In the same position as the smelting furnace, this is therefore its interpretation.

(B) 581027E,121055N: Anomaly with reading up to 8000ppm biased towards the eastern side of the survey. Interpreted as response from smelting workshop ditch.

(C) 581030E,121047N: Anomaly formed of two points of increased mag sus. One measuring up to 9000ppm, the other up to 13500ppm. Interpreted as the response from a possible working area associated with iron production.

Other observations:

-Areas around the anomalies have readings between 3000-5500ppm. This could be indicitive of the response to the natural geology.

Associations:

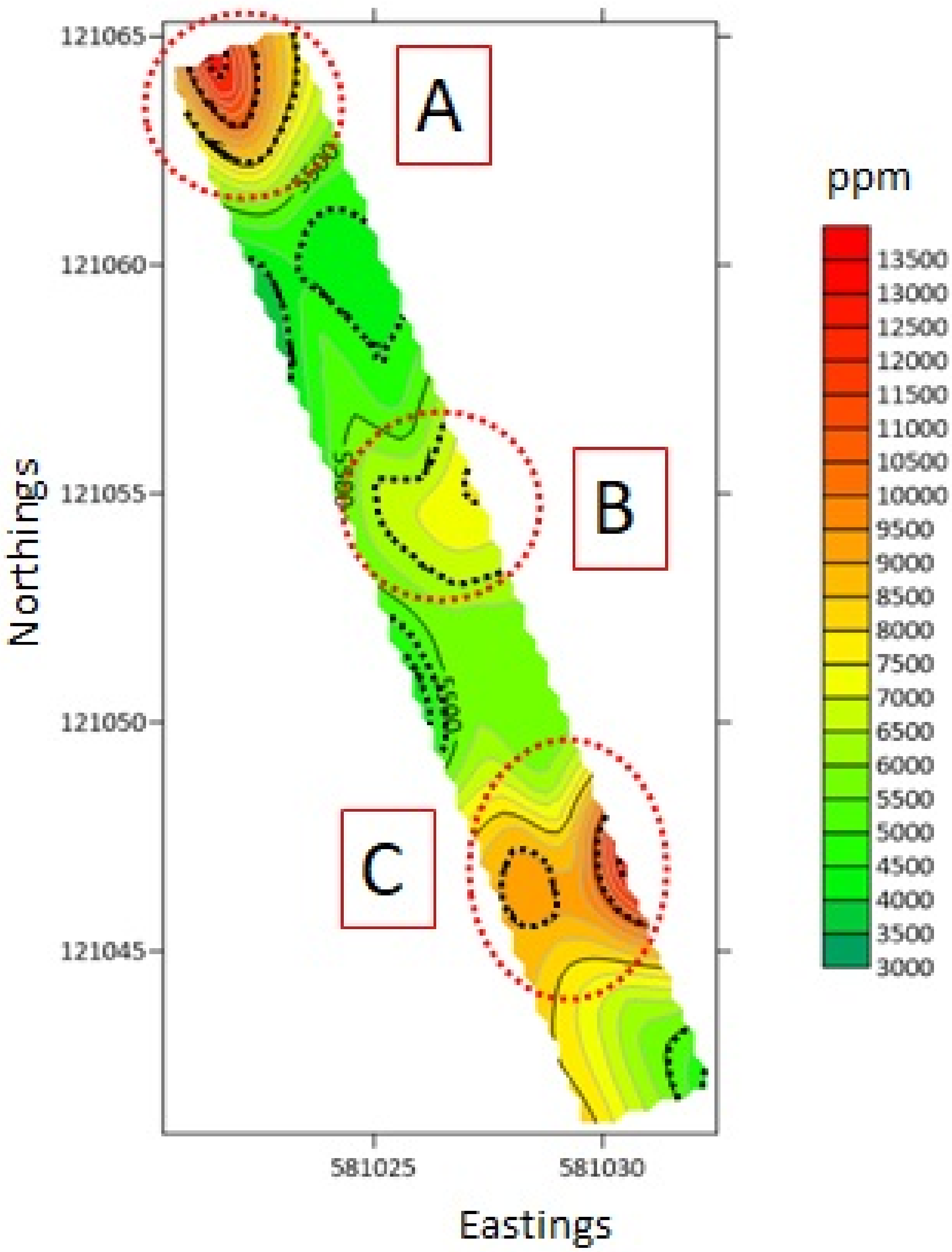

FIGURE A.64: In-phase 3kHz Field 1 Normalised and Annotated

Line CHF2-IN-15K

Anomalies:

(A) 581135E,121105N: Covering northern end of survey area of mag sus down to 1500ppm. In the position of the technological waste deposit.

(B) 581135E,121088N: A number of individual anomalies with readings around 6500ppm forming a line along the position of the smelting workshop ditch.

(C) 581130E,121083N: Linear feature with mag sus 8000ppm. Unclear of it represents a ditch or track feature.

(D) 581145E,121084N: An anomaly with mag sus readings up to 11000ppm which is believed to represent a possible working area associated with the smelting process.

Other observations:

- This survey covers the smelting workshop, therefore the furnaces identified in the magnetometer survey would be expected to be seen within this survey also.

Associations:

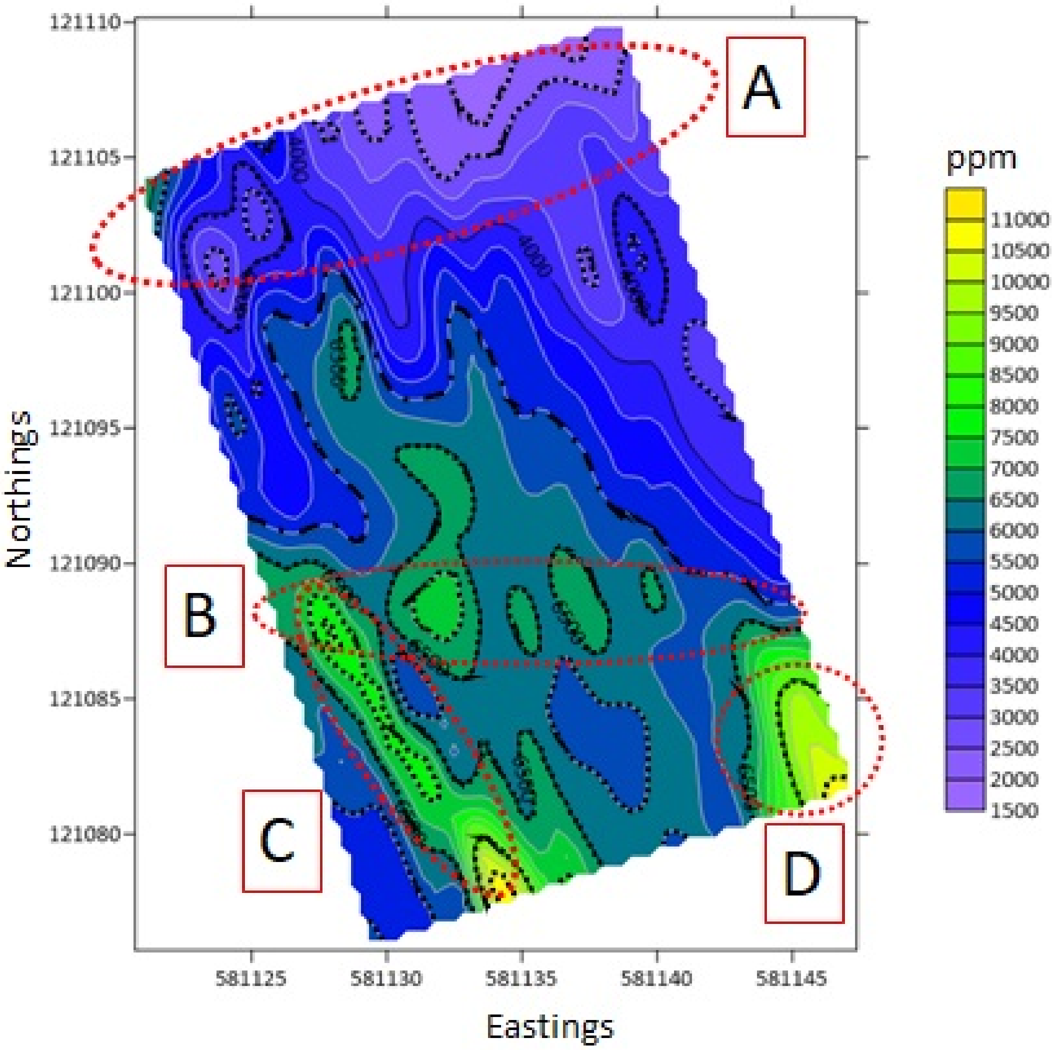

FIGURE A.65: In-phase 15kHz Field 2 Normalised and Annotated

Line CHF2-IN-3K

Anomalies:

(A) 581135E,121105N: Covering northern end of survey area of mag sus down to -2000ppm. In the position of the technological waste deposit.

(B) 581135E,121088N: A number of individual anomalies within an area with readings around 3000ppm forming a line along the position of the smelting workshop ditch.

(C) 581130E,121083N: Linear feature with mag sus 3000ppm. Unclear of it represents a ditch or track feature.

(D) 581145E,121084N: An anomaly with mag sus readings up to 7500ppm which is believed to represent a possible working area associated with the smelting process.

Other observations:

- This survey covers the smelting workshop, therefore the furnaces identified in the magnetometer survey would be expected to be seen within this survey also.

Associations:

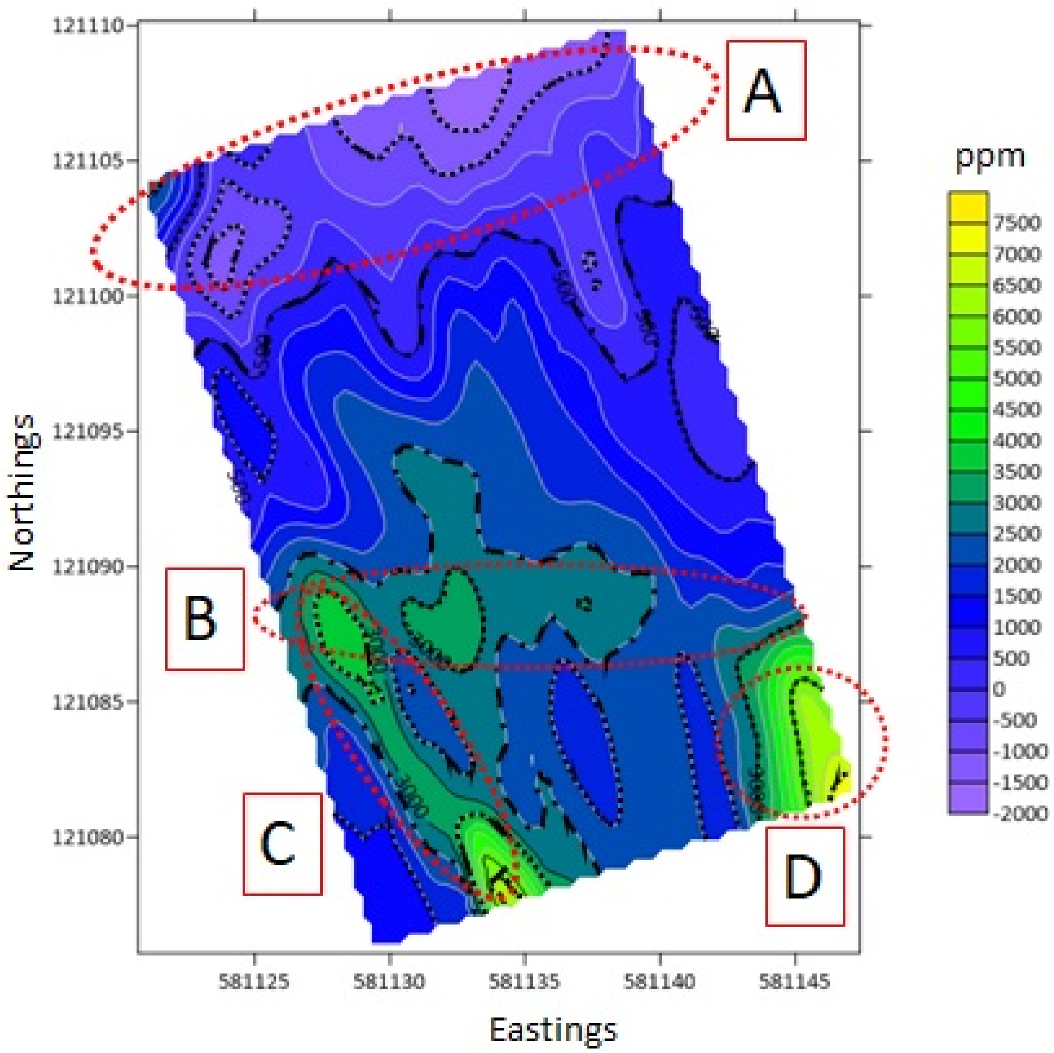

FIGURE A.66: In-phase 3kHz Field 2 Normalised and Annotated

Quadrature

Line CHF1-Q-15K

Anomalies:

(A) 581022E,121064N: Area of lower conductivity with a lowest reading of 0ppm. This is interpreted as the response from a smelting furnace.

(B) 581026E,121055N: Low conductivity anomaly with lowest readings of -20mS/s, biased towards the east of the survey area. In the position of the smelting workshop ditch.

(C) 581030E,121046N: Area consisting of two low conductivity anomalies with lowest readings of 10mS/s and -20ppm. This is interpreted as the response from a working area associated with iron production.

Other observations:

- Anomaly at 581026E,121052N has a similar response to the furnace, ditch, and working area. Could be a deposit of the same material that filling the other features.

Associations:

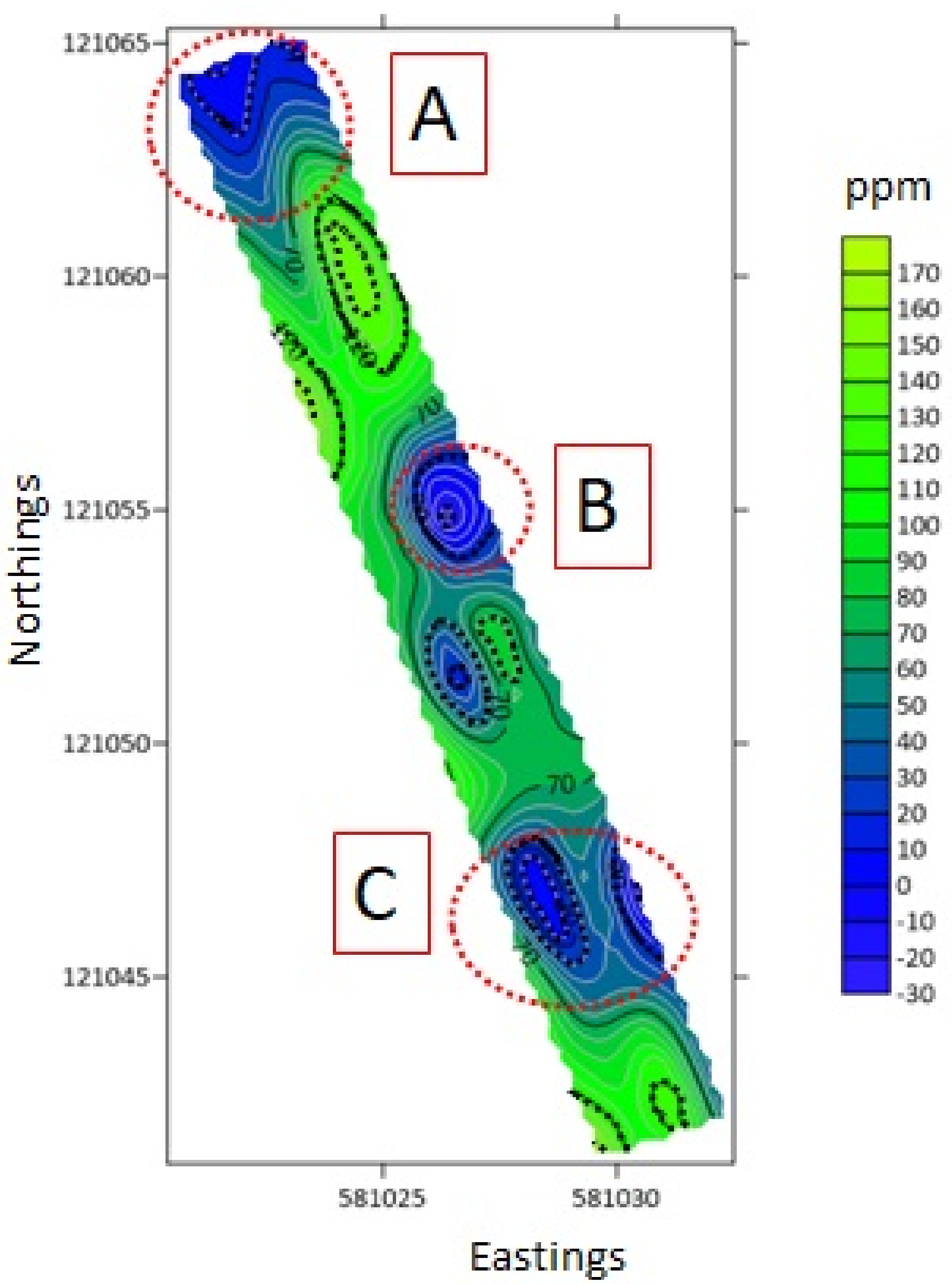

FIGURE A.67: Quadrature 15kHz Field 1 Normalised and Annotated

Line CHF1-Q-3K

Anomalies:

(A) 581022E,121064N: Area of lower conductivity with a lowest reading of -70ppm slightly biased to the west. This is interpreted as the response from a smelting furnace.

(B) 581026E,121055N: Low conductivity anomaly with lowest readings of -40mS/s, biased towards the east of the survey area. In the position of the smelting workshop ditch.

(C) 581030E,121046N: Area consisting of two low conductivity anomalies with lowest readings of -65mS/s and -75ppm. This is interpreted as the response from a working area associated with iron production.

Other observations:

-Anomaly at 581028E,121051N has a similar response to the furnace ditch. Could be a deposit of the same material or a similar type of infilled feature.

Associations:

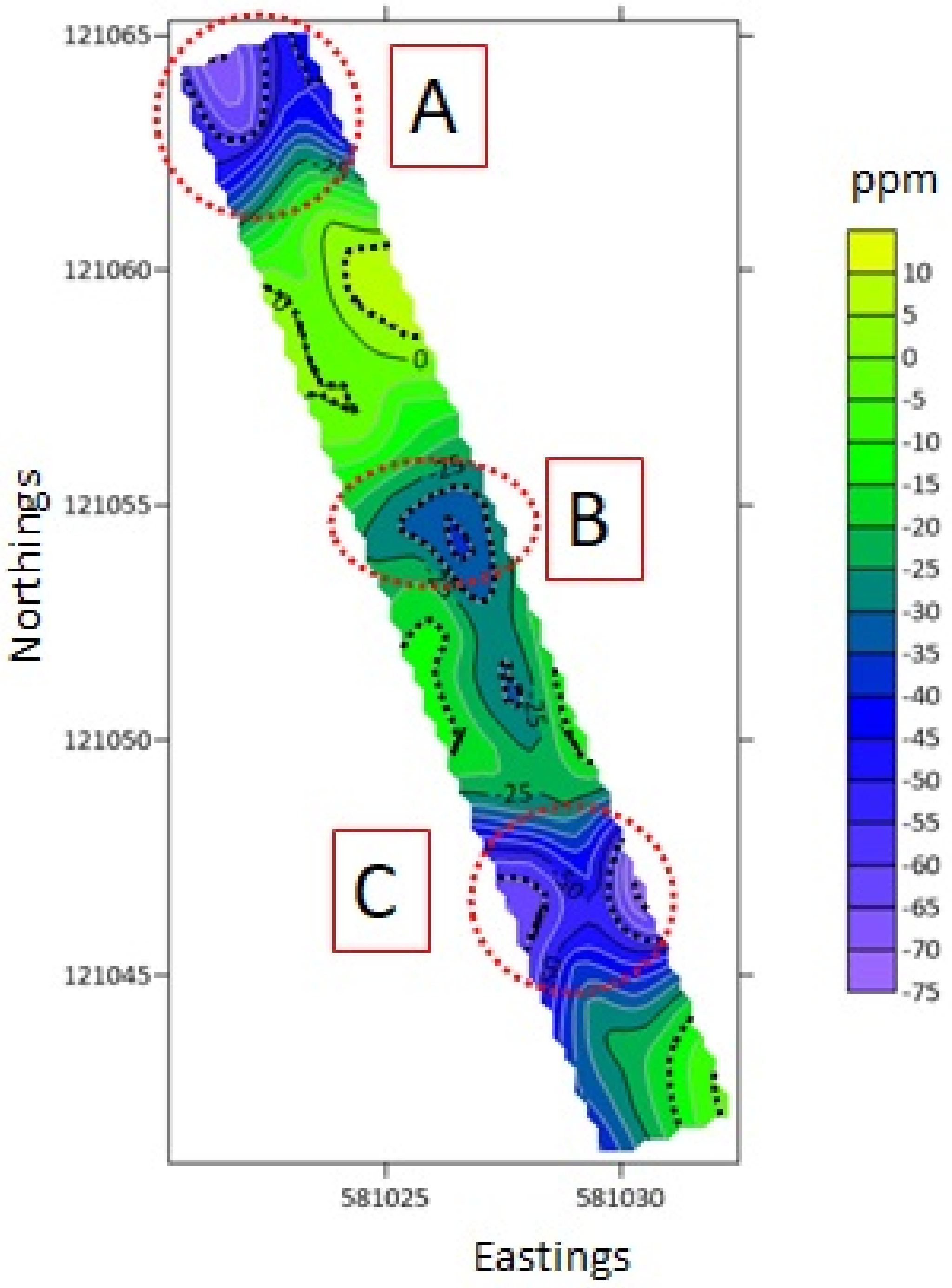

FIGURE A.68: Quadrature 3kHz Field 1 Normalised and Annotated

Line CHF2-Q-15K

Anomalies:

(A)581135E,121105N: Area of mixed conductivity with readings from 120ppm to -120ppm. Lower readings biased to the west. In the position of the technological waste deposit.

(B)581130E,121083N: Linear feature with readings around 160ppm. Unclear interpretation between ditch or trackway.

(C)581145E,121084N: Area of conductivity measuring around 160ppm. Matches with a feature in the magnetometer survey interpreted as a possible working area.

Other observations:

-Large area of increased conductivity covers the southern half of the survey with no clear interpretation.

-No evidence of the furnaces present according to the magnetometry survey.

Associations:

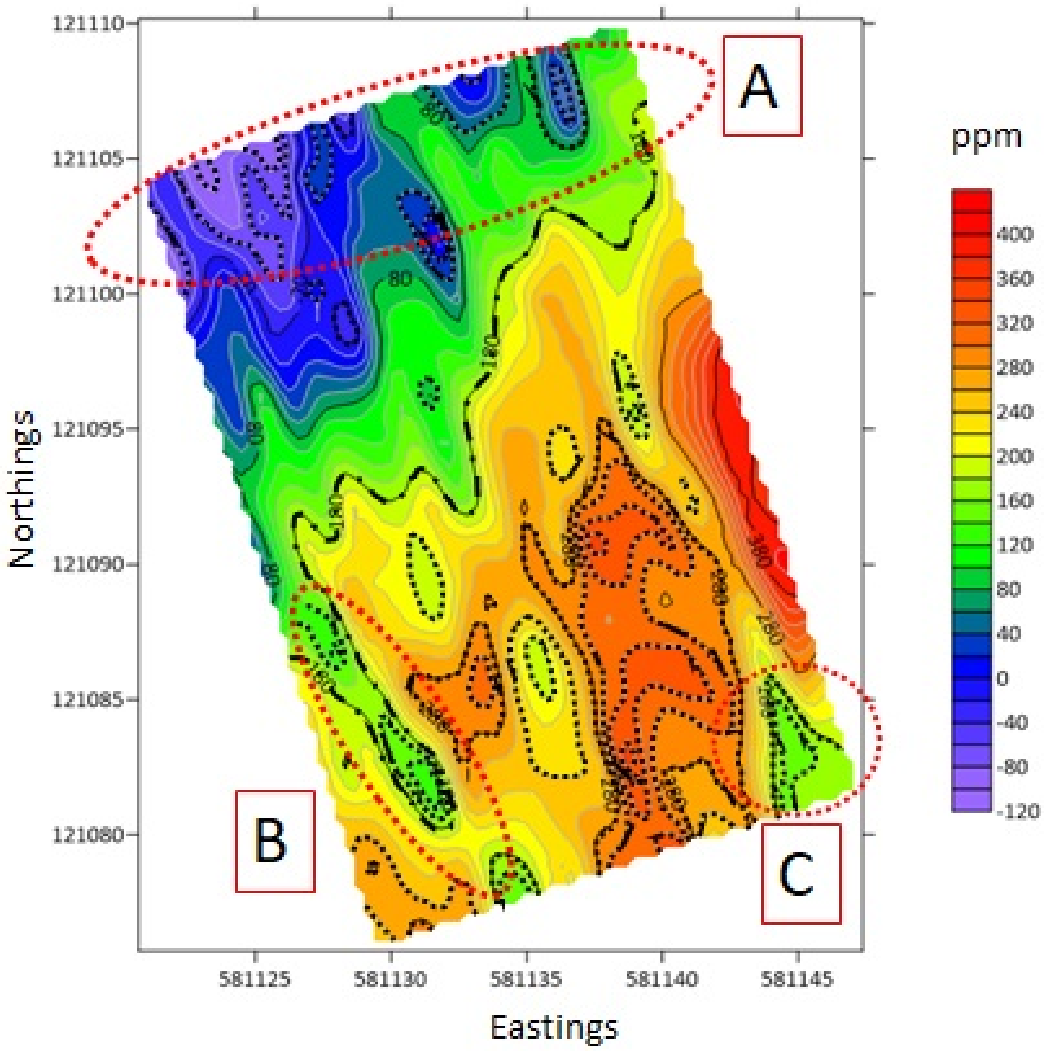

FIGURE A.69: Quadrature 15kHz Field 2 Normalised and Annotated

Line CHF2-Q-3K

Anomalies:

(A)581135E,121105N: Area of mixed conductivity with readings from 30ppm to -40ppm. Lower readings biased to the west. In the position of the technological waste deposit.

(B)581130E,121083N: Linear feature with readings around 35ppm. Unclear interpretation between ditch or trackway.

(C)581145E,121084N: Area of conductivity with lowest readings of -20ppm. Matches with a feature in the magnetometer survey interpreted as a possible working area.

Other observations:

-Large area of increased conductivity covers the southern half of the survey with no clear interpretation.

-No evidence of the furnaces present according to the magnetometry survey.

Associations:

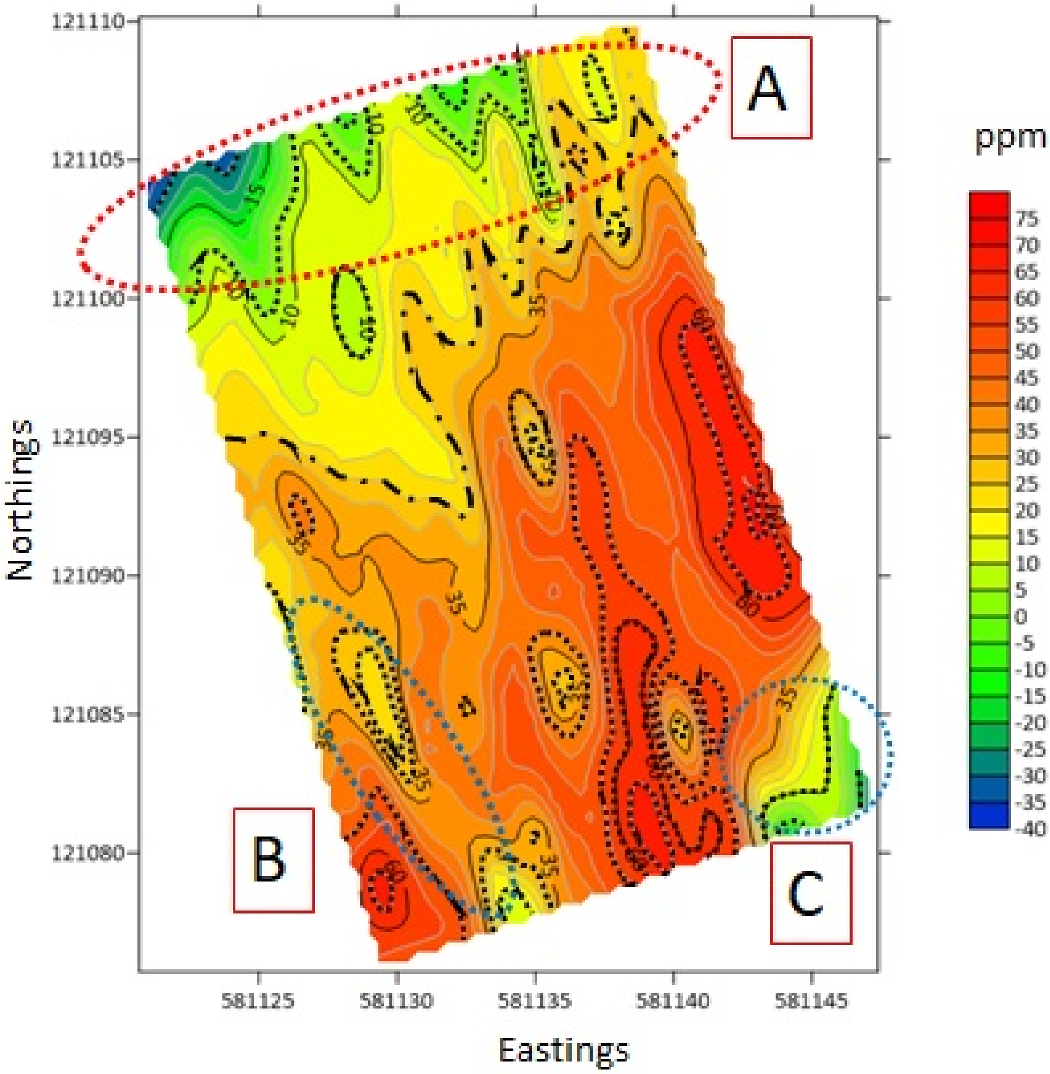

FIGURE A.70: Quadrature 3kHz Field 2 Normalised and Annotated

B Case Study 1 - Chitcombe - Excavation and Deposit Sampling

B.1 Excavation Strategy

1-The turf was removed and stored for reinstatement when the trench is backfilled.

2-The topsoil was removed with care being taken to not damage roots above 25mm thick.

3-Once it was believed the archaeological deposits were being reached the base surface of the trench was levelled

4-Nails and string were then placed around the bottom edge of the trench to deliminate the top of the spit allowing for a measure reference for excavation.

5-This was then photographed, and all paperwork and sample bags prepared for the spit.

Each sample bag noted site code, trench number, spit number and type of sample

6-The spit was then excavated using hand trowels to a depth of 0.1m with reference to the deliminating string.

7-All material excavated was weighed and recorded as initial weight.

. Any artefacts not directly related to iron production such as pottery was sampled separately to stop damage

8-The material was then sieved through a 6mm sieve

9-All material larger then 6mm was weighed, recorded and collected in its entirety.

10-All material to pass through the sieve was weighed, recorded and a 10% sample by weight taken.

11-All material not collected placed in a discard pile on a large tarp to keep grass clean.

12-Once spit excavated to a depth of 0.1m according to the deliminating string and all paperwork and sampling complete a new delimainating string was inserted.

13-Steps 5 to 12 were then repeated until the natural geology was reached.

14-Once trench fully excavated the trench sections were drawn along with trench plan if any features existed.

15-Once the excavation and all paperwork were completed the trench was backfilled and turf reinstated

B.2 Trench Outlines

TABLE B.1: CH16-1 trench overview

Trench	CH16-1
Length/Width	1mx1m
Depth	Max 0.55m
No. Spits	2
Context	101 – topsoil 102 – degraded technological waste, and ceramic
Description	Thin layer of degraded material – not waste heap – possible gravelling of area.

TABLE B.2: CH16-2 trench overview

Trench	CH16-2
Length/Width	1mx1m
Depth	Max 0.7m
No. Spits	6
Context	201 – topsoil 202 – dark charcoal layer 203 – sandy clay 204 – dark brown clay loam with FM and slag 205 – dark grey clay 206 – yellow sandy clay
Description	Deposits of technical waste mixed with redeposited clay. Victorian land drain discovered at base of trench on natural along with ceramic material and glass.

TABLE B.3: CH16-3 trench overview

Trench	CH16-3
Length/Width	
Depth	Max Min
No. Spits	NA
Context	301 – topsoil 302 – silty dark brown soil 303 – sandstone rubble 304 – natural yellow clay 305 – cut of trench
Description	Tile building remains

TABLE B.4: CH16-4 trench overview

Trench	CH16-4
Length/Width	
Depth	Max Min
No. Spits	NA
Context	401 – topsoil 402 – dark layer 403 – charcoal layer 404 – cut either side of posthole 405 – yellow clay loam debris post hole fill 406 – technical debris 407 – natural yellow/grey sandy clay 408 – cut of trench 409 – slag layer base of posthole
Description	High polarisation anomaly – large posthole

TABLE B.5: CH16-5 trench overview

Trench	CH16-5
Length/Width	
Depth	Max Min
No. Spits	NA
Context	501 – topsoil 502 – compact topsoil 503 – slag trackway 504 – grey brown silt ditch fill with increase slag in upper area 505 – technological waste 506 – yellow grey silt deposit inc geo and burnt clay 507 – dark black/brown silty fill inc ceramic and slag 508 – grey/black silt with friable clay inc occ slag 509 – natural
Description	Trackway

TABLE B.6: CH16-6 trench overview

Trench	CH16-6
Length/Width	
Depth	Max Min
No. Spits	NA
Context	601 – modern topsoil inc concrete fragments 602 – 'natural' topsoil 603 – charcoal rich loam inc slag and burnt clay 604 – mixed clay and burnt clay layer 605 – cinders 606 – yellow clay natural 607 – cut of trench
Description	In F3 near tile building – waste deposit

TABLE B.7: CH16-7 trench overview

Trench	CH16-7
Length/Width	
Depth	Max Min
No. Spits	NA
Context	701 – topsoil 702 – dark layer inc ceramic and charcoal 703 – loam ditch fill inc slag and charcoal 704 – rusty brown lens, iron rich 705 – yellow natural clay 706 – cut of trench
Description	Possible habitation/workshop areas

TABLE B.8: CH16-8 trench overview

Trench	CH16-8
Length/Width	
Depth	Max Min
No. Spits	NA
Context	801 802 803
Description	

TABLE B.9: CH16-9 trench overview

Trench	CH16-9
Length/Width	
Depth	Max Min
No. Spits	NA
Context	901 – topsoil 902 – ditch fill 903 – small ditch/pit 904 – post hole? 905 – natural 906 – cut of trench
Description	Smelting workshop ditch Field 2

TABLE B.10: CH16-10 trench overview

Trench	CH16-10
Length/Width	
Depth	Max Min
No. Spits	NA
Context	1001 – top soil 1002 – ploughed soil 1003 – dark brown/black 1004 – grey/brown lens 1005 – grey/brown water degraded clay layer
Description	Area between furnaces – possible post holes – very clean of smelting debris

TABLE B.11: CH16-11 trench overview

Trench	CH16-11
Length/Width	
Depth	Max Min
No. Spits	NA
Context	1101 – topsoil 1102 – dense slag 1103 - natural
Description	Area top of F2 trackway?

TABLE B.12: CH16-12 trench overview

Trench	CH16-12
Length/Width	
Depth	Max Min
No. Spits	NA
Context	1201 – topsoil 1202 – redeposited yellow natural clay 1203 – furnace?? 1204 – natural clay 1205 – cut of trench 1206 – natural under furnace in slot
Description	Possible Furnace

TABLE B.13: CH16-13 trench overview

Trench	CH16-13
Length/Width	1mx1m
Depth	Max 0.6m
No. Spits	4
Context	1301 – topsoil 1302 – dark clay loam with tech waste
Description	Deposit of technological waste but not believed to be true waste heap.

TABLE B.14: CH16-14 trench overview

Trench	CH16-14
Length/Width	1mx1m
Depth	Max 1.9m
No. Spits	15
Context	1401 – topsoil 1402 – brown clay loam with increase slag 1403 – brown clay loam with increase furnace material 1404 – slag rich layer with high amount of voids between slag 1405 – hard compact slag layer in a dark matrix 1406 – dark charcoal rich layer with technical waste
Description	Entire depth of technological waste heap

TABLE B.15: CH16-15 trench overview

Trench	CH16-15
Length/Width	
Depth	Max Min
No. Spits	NA
Context	1501 – topsoil 1502 – loam with slag 1503 – yellow clay with inclusions 1504 – brown loam 1505 – grey clay 1506 – dark loam
Description	Beamslot

TABLE B.16: CH16-16 trench overview

Trench	CH16-16
Length/Width	
Depth	Max Min
No. Spits	NA
Context	1601 – topsoil 1602 – yellow clay with slag and burnt clay 1603 – bank robber trench 1604 – yellow sandy clay natural
Description	Beamslot

TABLE B.17: CH16-17 trench overview

Trench	CH16-17
Length/Width	2mx0.5m
Depth	Max Min
No. Spits	NA
Context	1701 – topsoil 1702 – similar to topsoil with increased amount of geological material 1703 – hard compact layer formed of slag and burnt clay with increased charcoal 1704 – 'beam slot' EW yellow and pink clay 1705 – 'beam slot' NS natural yellow clay filled with dark organic material
Description	Beam slot south of stone building – bead discovered

TABLE B.18: CH17-18 trench overview

Trench	CH17-18
Length/Width	4mx4.5m
Depth	Max Min
No. Spits	NA
Context	1801 – homogenous brown topsoil inc slag and ceramic 1802 – charcoal rich post hole cut 1803 – repeating layers of yellow/pink stain/grey clay, inc charcoal and small slag 1804 – redeposit of yellow/pink clay inc charcoal 1805 – redeposit of yellow clay inc charcoal 1806 – topsoil clay mix 1807 – yellow sandy clay natural
Description	Iron production furnace – redeposited cyclical build up at front – ore rich filling to furnace – possible rebuilding of furnace or built in permanent setting

TABLE B.19: CH17-19 trench overview

Trench	CH17-19
Length/Width	4mx0.5m
Depth	Max Min
No. Spits	NA
Context	1901 – topsoil 1902 – high % charcoal inc ceramic and glass 1903 – grey/brown loam with clay and charcoal inc geo increase at north end 1904 – reddish/brown deposit with high % iron-stone/ore 1905 – 'wall' feature formed of large stone and slag sitting on cut ledge in natural 1906 – rubble/stone layer inc slag in bottom of trench to south of 1905
Description	Smelting workshop ditch Field one

TABLE B.20: CH17-20 trench overview

Trench	CH17-20
Length/Width	
Depth	Max Min
No. Spits	NA
Context	2001 – topsoil 2002 – burnt geo (ironstone), burnt clay and small slag 2003 – smaller slag and geo 2004 – slag and geo 2005 – yellow sandy clay natural
Description	Magnetic anomaly high amount of roasted ore possible workshop

TABLE B.21: CH17-21 trench overview

Trench	CH17-21
Length/Width	2.5mx0.5m
Depth	Max Min
No. Spits	NA
Context	2101 – topsoil 2102 – thin lens of slag 2103 – compact layer of burnt geo material (ironstone) 2104 – band of small slag with burnt pink/orange clay 2105 – charcoal spread inc small slag and burnt clay 2106 – deposit of burnt clay, slag and charcoal 2107 – compressed charcoal layer 2108 – yellow sandy/clay natural
Description	Highly magnetic area possible working area

TABLE B.22: CH17-22 trench overview

Trench	CH17-22
Length/Width	2mx2m
Depth	Max Min
No. Spits	NA
Context	2201 – topsoil 2202 – slaggy spread across surface of ditch 2203 – ditch fill 2204 – charcoal and ash rich fill 2205 – ditch filled with 2203 2206 – depression south side of trench filled with 2204
Description	Southeast corner of smelting workshop ditch field one

TABLE B.23: CH17-23 trench overview

Trench	CH17-23
Length/Width	1mx1m
Depth	Max Min
No. Spits	NA
Context	2301 - topsoil 2302 – red/grey natural mix inc furnace material 2303 – grey fine silt layer surrounding 'wall' (2306) 2304 – similar to 2302 2305 – post hold fill 2306 – fill of ditch? Large mix slag deposited stacking up 2307 – natural at bottom of posthole
Description	High magnetic anomaly centre and south of furnaces. Large posthole with various packing – possible smithing debris

TABLE B.24: CH17-24 trench overview

Trench	CH17-24
Length/Width	3mx0.5m
Depth	Max Min
No. Spits	NA
Context	2401 - topsoil 2402 – slag fill
Description	Potential rectilinear feature, small slag filled ditch – foundation trench?

TABLE B.25: CH17-25 trench overview

Trench	CH17-25
Length/Width	2mx0.5m
Depth	Max Min
No. Spits	NA
Context	2501 – topsoil 2502 – slag layer 2503 – yellow sandy clay natural
Description	Further assessing rectilinear feature in CH17-24

TABLE B.26: CH17-26 trench overview

Trench	CH17-26
Length/Width	1mx1m
Depth	Max Min
No. Spits	NA
Context	2601 – topsoil 2602 – land drain 2603 – yellow sandy clay ledge under 2602 2604 – Stoney layer 2605 – slag and stone layer 2606 – sandy clay natural
Description	In woods east of building to see if continuation – slag and land-drain

TABLE B.27: CH17-27 trench overview

Trench	CH17-27
Length/Width	3.5mx0.5m
Depth	Max Min
No. Spits	NA
Context	2701 – topsoil 2702 – burnt clay layer inc slag 2703 – slag layer inc burnt clay and charcoal 2704 – charcoal rich layer 2705 – silty dark grey ditch fill in south of trench inc charcoal and slag 2706 – yellow/brown clay redeposit/cap 2707 – charcoal rich ditch fill on norther side of ditch 2708 – silty layer below 2704 in south of ditch
Description	smelting workshop ditch field one

TABLE B.28: CH17-28 trench overview

Trench	CH17-28
Length/Width	1mx1m
Depth	Max Min
No. Spits	NA
Context	2801 - topsoil 2802 – compact layer of slag, burnt clay and charcoal 2803 - natural
Description	Thought to be extension/return of ditch around furnaces, looks to be water degraded, probable run off downhill causing feature

TABLE B.29: CH17-29 trench overview

Trench	CH17-29
Length/Width	3mx0.5m
Depth	Max Min
No. Spits	NA
Context	2901 – topsoil 2902 – very compact slag layer, ingression of topsoil, inc furnace material 2903 – thin lens of slit inc ceramic 2904 – charcoal rich silt fill bottom of ditch inc ceramic
Description	Possible extension of ditch surrounding furnaces – ditch feature with large piece of slag – large evidence of charcoal in base.

TABLE B.30: CH17-30 trench overview

Trench	CH17-30
Length/Width	3mx0.5m
Depth	Max Min
No. Spits	NA
Context	3001 – topsoil brown homogenous layer, clay/loam, contain ceramic and slag 3002 – 'crispy layer' brown homogenous clay/loam same as topsoil with increased slag, include ceramic 3003 – sandy dark brown/black, silty charcoal stained silt, ditch open, inc ceramic 3004 – sandy dark brown black, silty charcoal fill. Inc slag 3005 – white sandy band 3006 – natural sandy clay yellow
Description	Double ditch in field 2 to asses if habitation nearby.

B.2.1 Section drawings

Trench 1

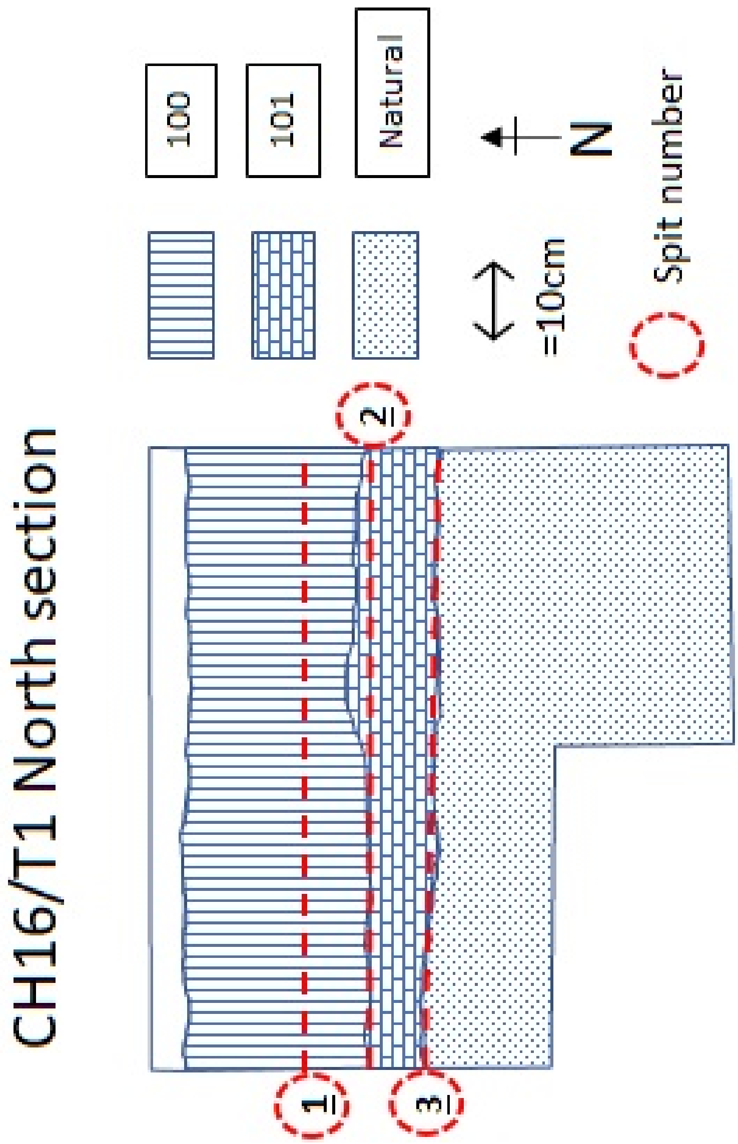

FIGURE B.1: Chitcombe Trench 1 north section drawing

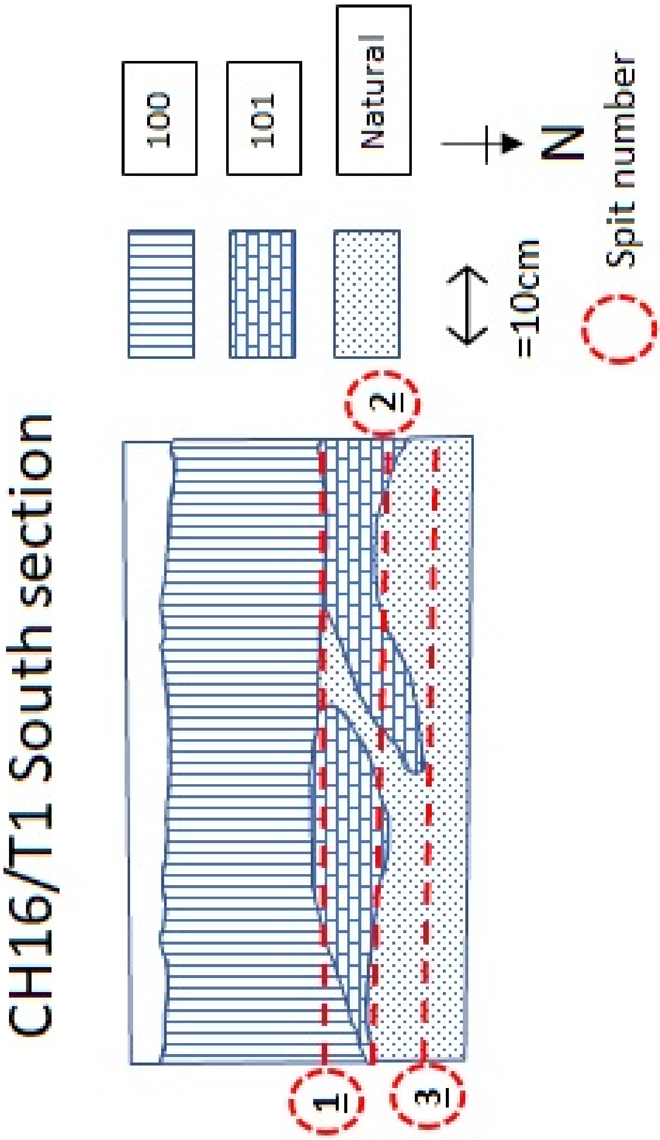

FIGURE B.2: Chitcombe trench 1 south section drawing

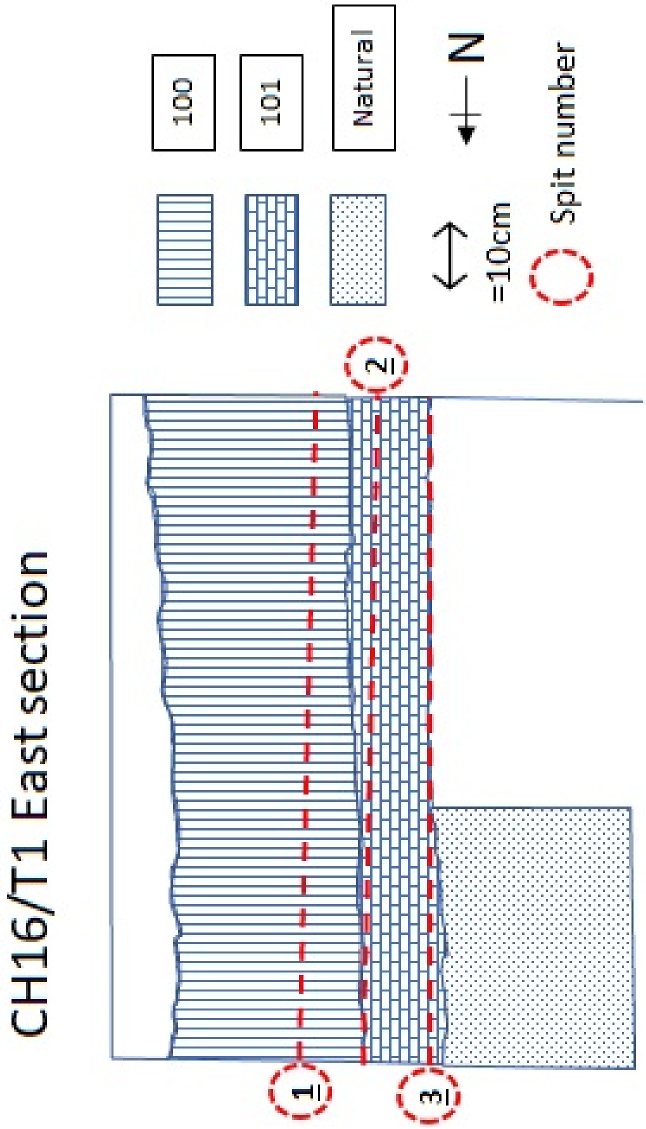

FIGURE B.3: Chitcombe trench 1 east section drawing

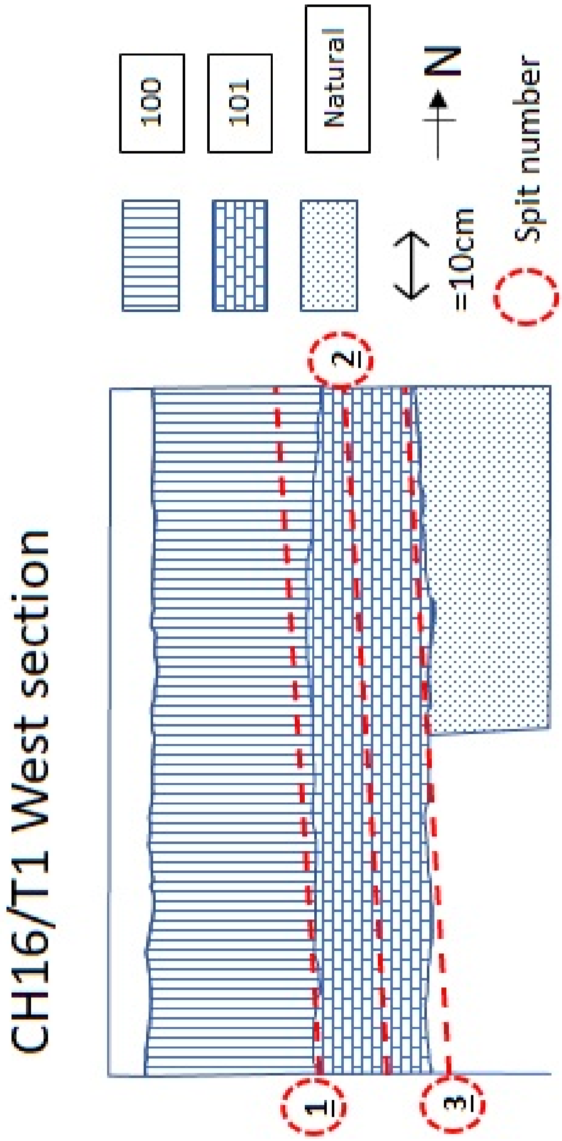

FIGURE B.4: Chitcombe trench 1 west section drawing

Trench 2

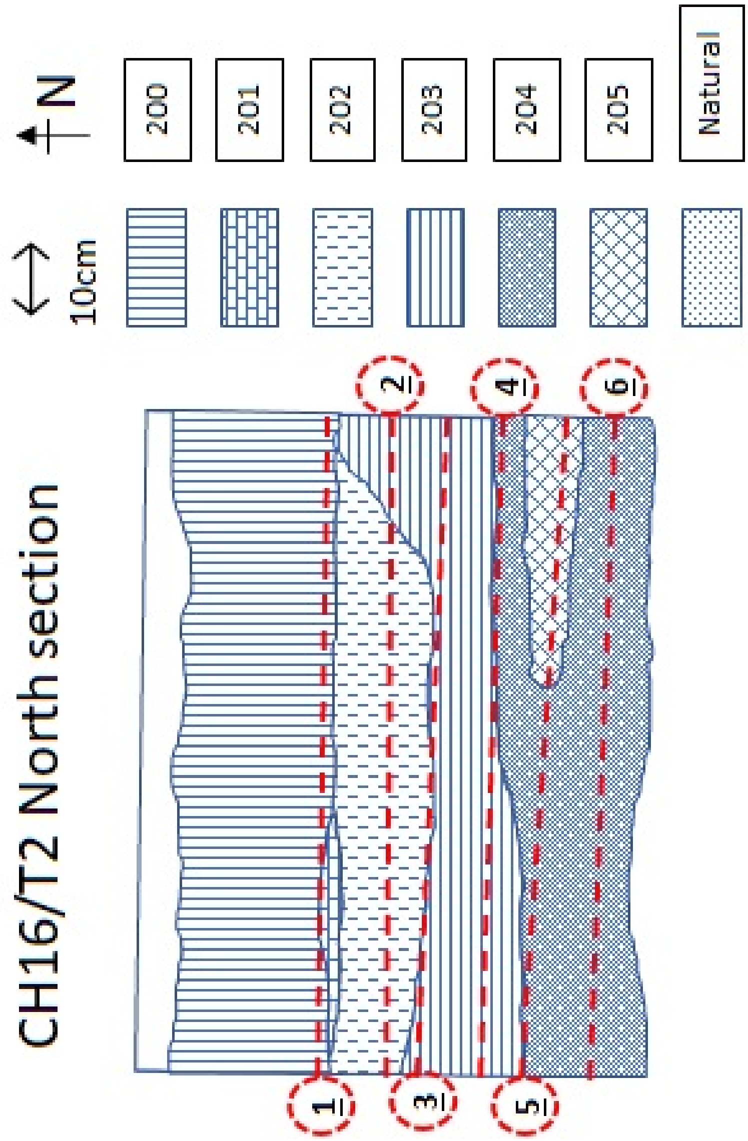

FIGURE B.5: Chitcombe Trench 2 north section drawing

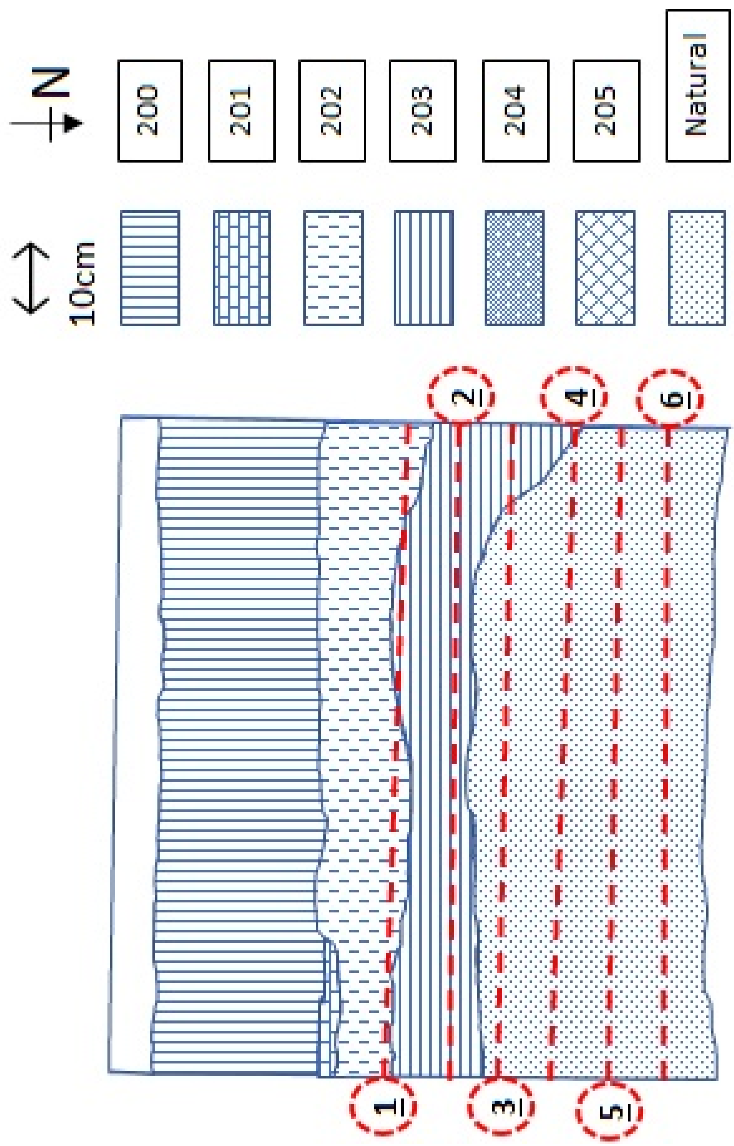

FIGURE B.6: Chitcombe trench 2 south section drawing

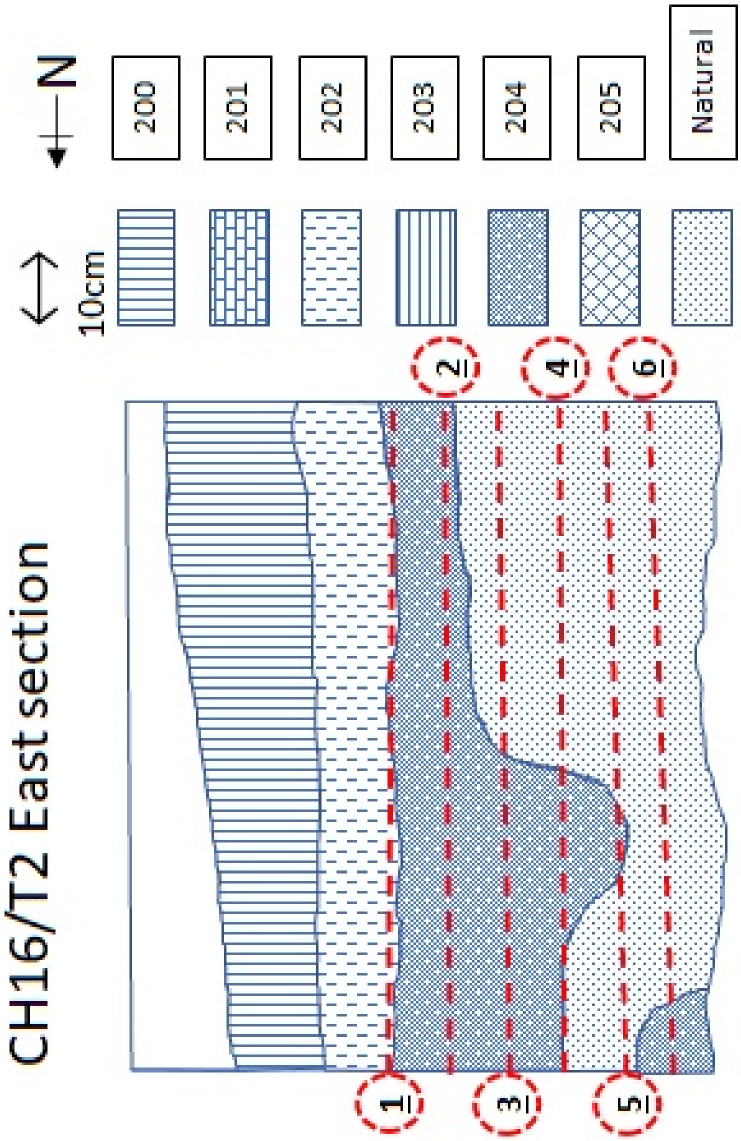

FIGURE B.7: Chitcombe trench 2 east section drawing

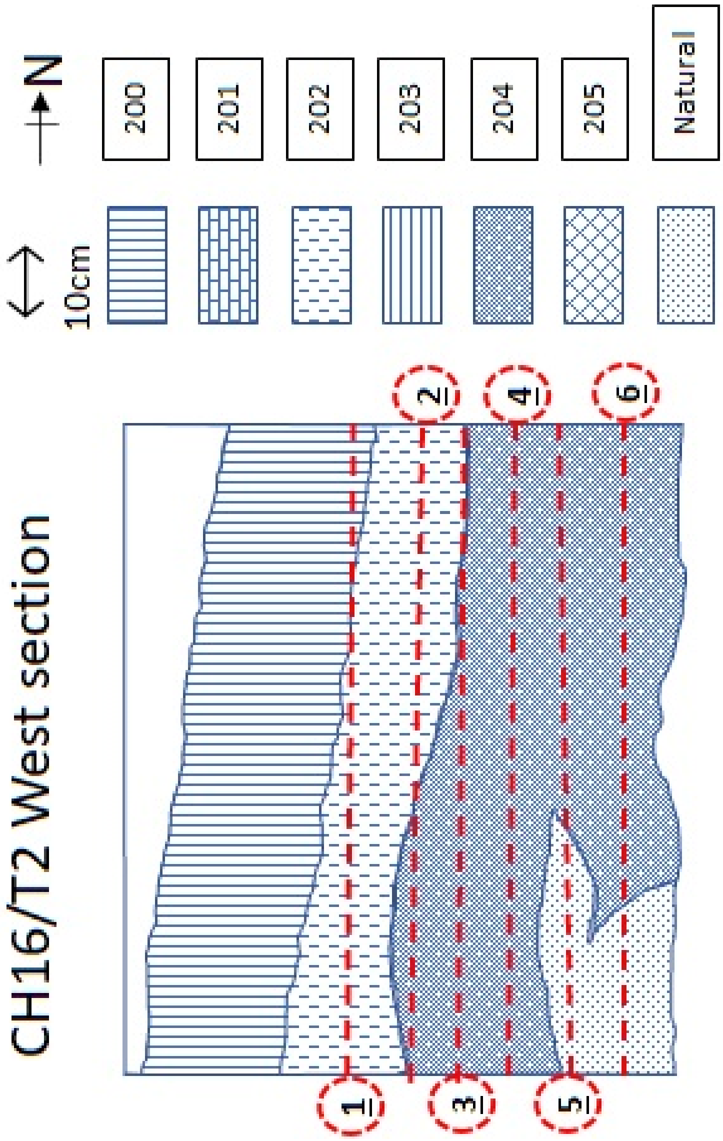

FIGURE B.8: Chitcombe trench 2 west section drawing

Trench 13

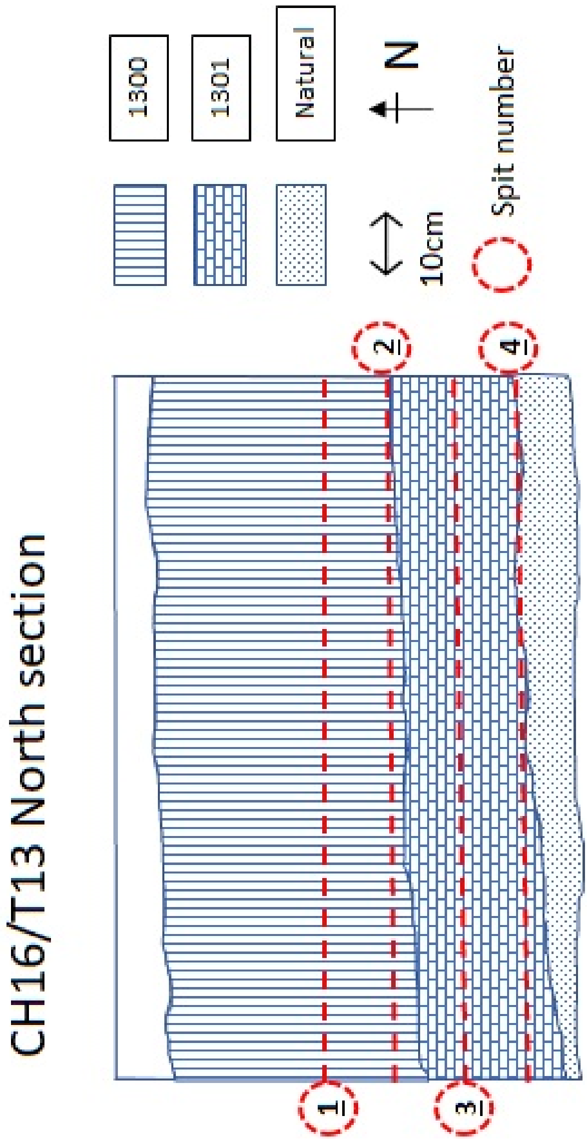

FIGURE B.9: Chitcombe Trench 13 north section drawing

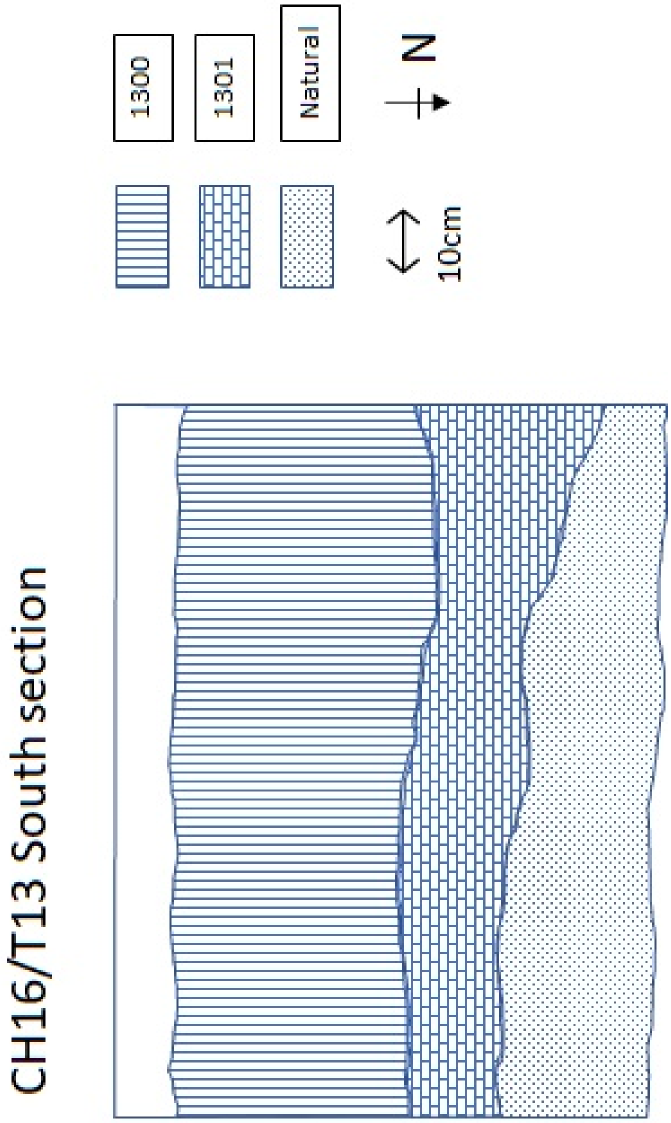

FIGURE B.10: Chitcombe trench 13 south section drawing

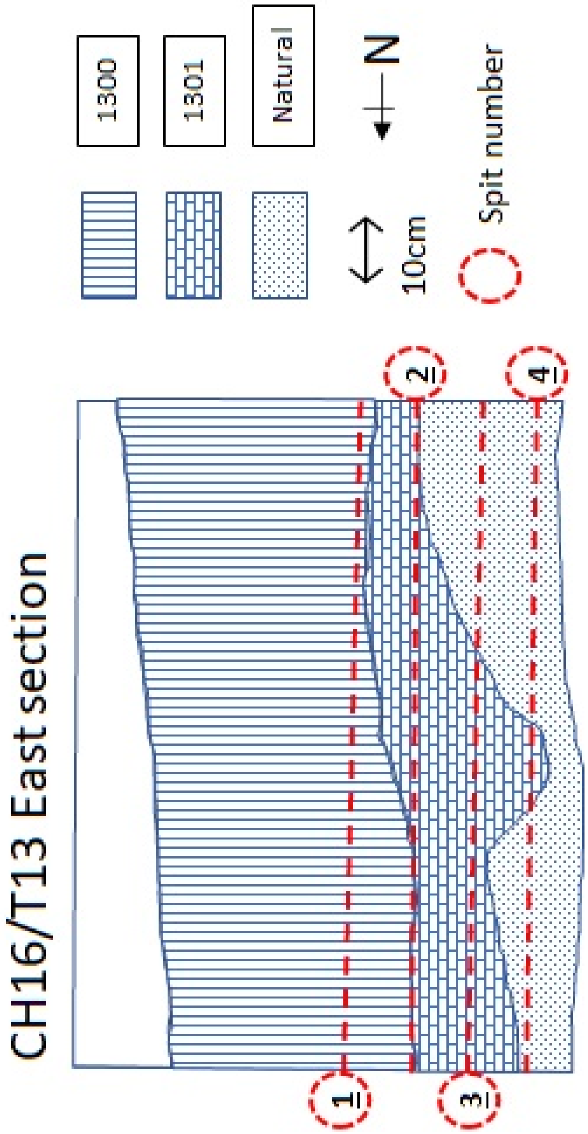

FIGURE B.11: Chitcombe trench 13 east section drawing

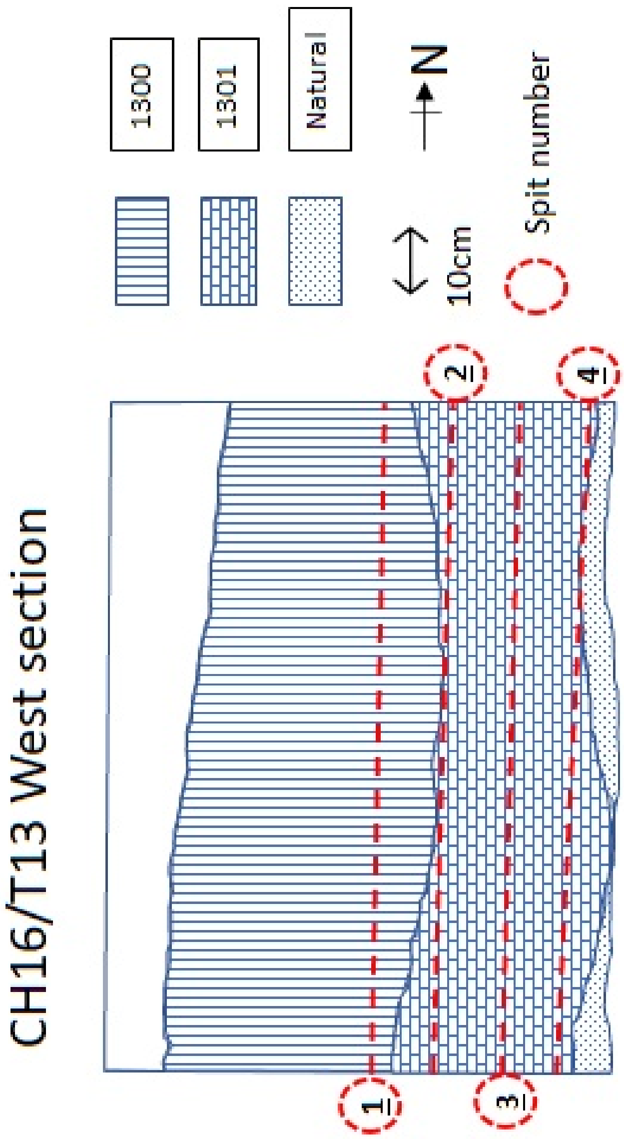

FIGURE B.12: Chitcombe trench 13 west section drawing

Trench 14

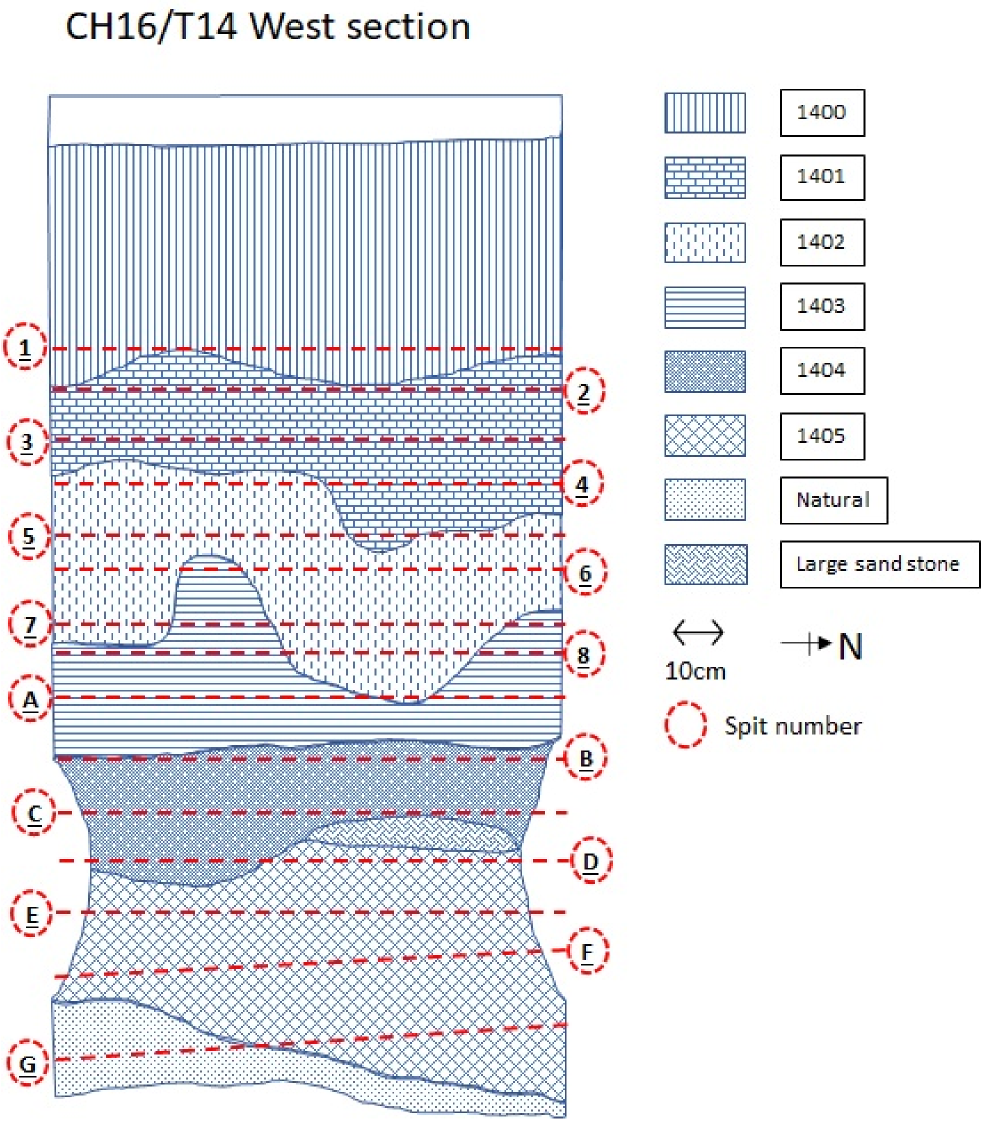

FIGURE B.13: West section drawing for Chitcombe Trench 14

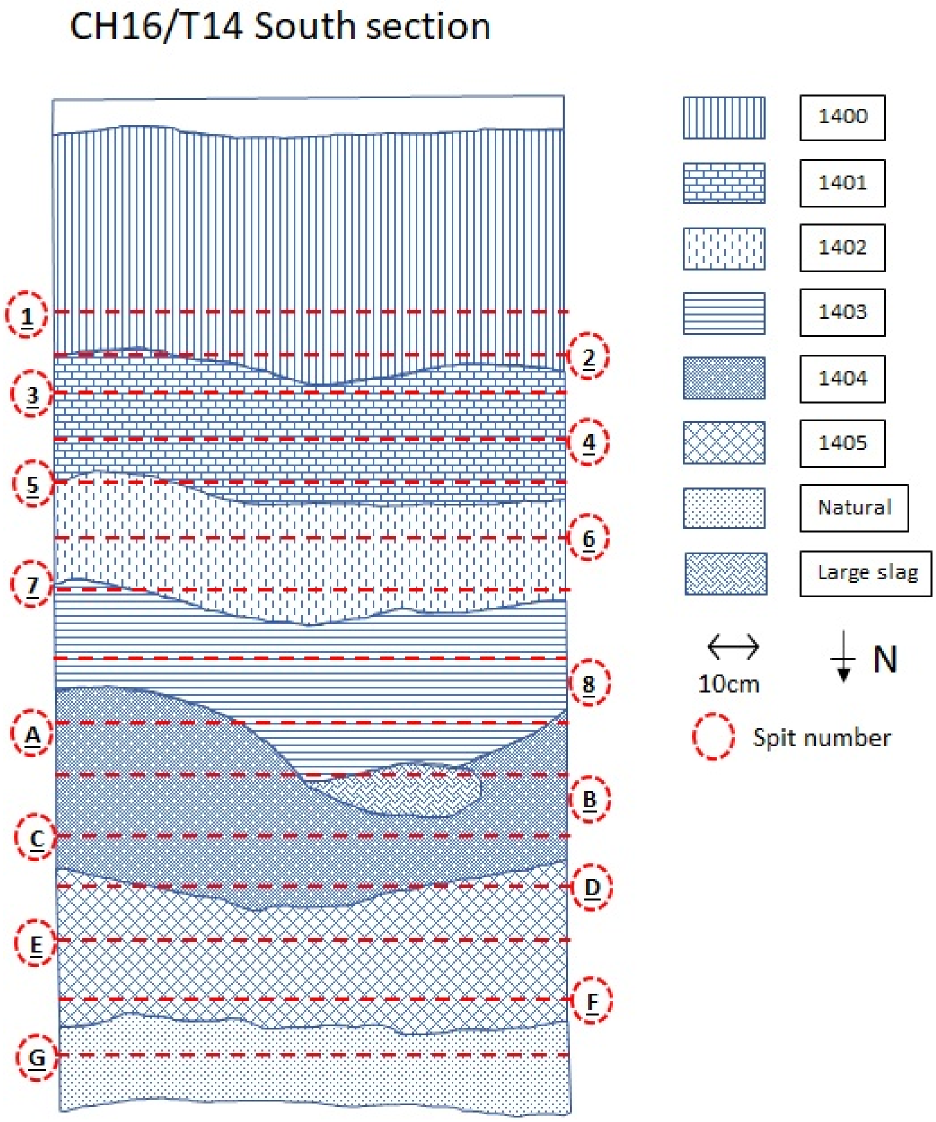

FIGURE B.14: south section drawing for Chitcombe Trench 14

B.3 Quantification

TABLE B.31: Abbreviations used in quantification tables with definitions

name	abbreviation	definition
excavated material	EMa	all material excavated
Inclusions	Inc	material >6mm
mixed large	MLa	combination of large + MMa >25mm<6mm
mixed small	MSm	combination of small + MMa <25mm
mixed matrix	MMa	combination of matrix + FR <6mm
large	large	clean material >25mm
small	small	clean material <25mm>6mm
matrix	matrix	clean material <6mm>50μ
fine residue	FR	material <50μ
furnace material	FM	furnace material
geological	geo	geological material
not available	NA	data unavailable, reason below graph

B.3.1 Excavation weights

TABLE B.32: Chitcombe trench excavation weights (kg)

trench	spit	EMa	MMa	Inc	Mla	MSm
1	1	102.80	76.95	25.85	NA	NA
1	2	131.10	98.30	32.80	NA	NA
1 total	all	233.90	175.25	58.65	NA	NA
2	1	148.00	76.75	71.25	NA	NA
2	2	162.50	107.35	55.15	NA	NA
2	3	115.80	67.40	48.40	NA	NA
2	4	137.00	102.70	34.30	NA	NA
2	5	125.30	96.00	29.30	NA	NA
2	6	98.40	85.40	13.00	NA	NA
2 total	all	787.00	535.60	251.40	NA	NA
13	1	140.75	114.00	26.75	NA	NA
13	2	203.80	158.50	45.30	NA	NA
13	3	199.10	170.85	28.25	NA	NA
13	4	14.63	146.25	0	NA	NA
13 total	all	689.90	589.60	100.30	NA	NA
14	1	96.10	58.45	37.65	NA	NA
14	2	148.60	65.50	83.10	NA	NA
14	3	131.80	48.60	83.20	NA	NA
14	4	142.85	69.60	73.25	NA	NA
14	5	129.30	51.20	78.10	NA	NA
14	6	139.70	37.25	102.45	NA	NA
14	7	132.30	29.50	102.80	NA	NA
14	8	338.50	28.30	310.20	NA	NA
14	A	142.90	27.95	114.95	92.45	22.50
14	B	118.60	29.65	88.95	NA	NA
14	C	94.75	37.15	57.60	37.40	20.20
14	D	75.40	28.60	46.80	NA	NA
14	E	82.60	26.50	56.10	34.30	21.80
14	F	139.50	51.55	87.95	NA	NA
14	G	104.90	32.80	72.10	NA	NA
14 total	all	2017.80	622.60	1395.20	NA	NA
site total	all	3494.70	1747.80	1746.90	NA	NA

Table of abbreviations at beginning of section

B.3.2 Large samples

TABLE B.33: Chitcombe T14 - Quantification of mixed large (kg)

spit	MLa	large	slag	FM	geo	MMa	total
1	NA	18.26	17.41	0.85	0	NA	NA
3	NA	46.96	41.07	5.88	0.02	NA	NA
5	NA	39.67	33.14	6.53	0	NA	NA
7	NA	59.94	57.99	1.95	0	NA	NA
A	92.45	76.49	74.27	0.31	1.91	15.96	92.45
C	37.40	23.74	22.36	1.38	0	13.66	37.40
E	34.30	22.77	15.82	6.00	0.95	11.53	34.30
total	NA	287.83	262.06	22.89	2.88	NA	NA

Table of abbreviations at beginning of section

This table is split between spit 7 and A as this is where the change in method occurred with the addition of the 6mm sieve

The way in which the material in spits 1-7 was collected and processed means there is no weight measurements for the 'mixed large' and 'mixed matrix' categories

B.3.3 Small samples

Analysed samples

TABLE B.34: Chitcombe Trench 14 - Quantification of Small sample weights by material and spit - Spit 1-7 complete, Spit A-E 1kg sub-sample (kg)

Spit	MSm	small	slag	FM	geo	MMa	total
1	NA	9.30	7.80	0.50	0.90	NA	NA
3	NA	16.20	13.70	1.40	1.10	NA	NA
5	NA	10.50	4.70	4.80	1.00	NA	NA
7	NA	24.50	21.75	1.55	1.20	NA	NA
total	NA	60.50	47.95	8.25	4.20	NA	NA
A	1.000	0.864	0.838	0.013	0.013	0.136	1.000
C	1.000	0.678	0.646	0.021	0.011	0.322	1.000
E	1.000	0.587	0.430	0.0115	0.042	0.413	1.000
total	3.000	2.350	1.914	0.149	0.066	0.871	3.000

This table is split between spit 7 and A as this is where the change in method occurred with the addition of the 6mm sieve

Due to this change there is no weight measurement for the 'mixed small' and 'mixed matrix' for spit 1-7.

Across spits A-E 1kg samples were taken of the 'mixed small' which were then washed and sorted as described in chapter 5, with the data presented here.

Complete totals cannot be calculated as the sampling between the spits was different.

Small Extrapolated Samples

TABLE B.35: Chitcombe Trench 14 - Quantification of extrapolated mixed small material by spit level (kg)

Spit	MSm	small	slag	FM	geo	MMa	total
1	NA	9.30	7.80	0.50	0.90	NA	NA
3	NA	16.20	13.70	1.40	1.10	NA	NA
5	NA	10.50	4.70	4.80	1.00	NA	NA
7	NA	24.50	21.75	1.55	1.20	NA	NA
A	22.50	19.45	18.86	0.30	0.30	3.05	22.50
C	20.20	13.69	13.05	0.42	0.22	6.51	20.20
E	21.80	12.79	9.38	2.51	0.91	9.01	21.80
total	NA	106.43	89.24	11.47	5.62	NA	NA

B.3.4 Matrix samples

Analysed Samples

TABLE B.36: Chitcombe Trench 14 - Quantification of 1kg sample of mixed matrix by spit level (kg)

Spit	MMa	matrix	Slag	FM	Geo	FR	total
1	1.000	0.050	0.015	0.005	0.030	0.950	1.000
3	1.000	0.075	0.021	0.006	0.048	0.925	1.000
5	1.000	0.100	0.030	0.009	0.061	0.900	1.000
7	1.000	0.050	0.018	0.005	0.027	0.950	1.000
A	1.000	0.150	0.065	0.014	0.071	0.850	1.000
C	1.000	0.200	0.148	0.011	0.041	0.800	1.000
E	1.000	0.200	0.064	0.024	0.112	0.800	1.000
total	7.000	0.825	0.361	0.390	0.074	6.175	7.000

Extrapolated Samples

TABLE B.37: Chitcombe Trench 14 - Quantification of extrapolated mixed matrix by spit level (kg)

Spit	MMa	matrix	slag	FM	Geo	FR	total
1	68.54	3.43	1.03	0.34	2.06	65.11	68.54
3	68.64	5.15	1.44	0.41	3.30	63.49	68.64
5	79.14	7.91	2.37	0.71	4.83	71.22	79.14
7	47.86	2.39	0.86	0.24	1.29	45.46	47.86
A	46.96	7.04	3.05	0.66	3.33	39.92	46.96
C	57.32	11.46	8.48	0.63	2.35	45.86	57.32
E	47.04	9.41	3.01	1.13	5.27	37.63	47.04
total	415.50	46.80	20.25	4.12	22.42	368.70	415.50

B.3.5 Material weights

Total Slag

TABLE B.38: Chitcombe Trench 14 - Quantification of slag by spit level (kg)

spit	spit weight	large	small	matrix	total
1	96.10	17.41	7.80	1.03	26.24
3	131.80	41.07	13.70	1.44	56.21
5	129.30	33.14	4.70	2.37	40.21
7	132.30	57.99	21.75	0.86	80.60
A	142.90	74.27	18.86	3.05	96.18
C	94.75	22.36	13.05	8.48	43.89
E	82.60	15.82	9.38	3.01	28.21
total	809.75	262.06	89.24	20.25	371.55

Total Furnace Material

TABLE B.39: Chitcombe Trench 14 - Quantification of furnace material by spit level (kg)

spit	spit weight	large	small	matrix	total
1	961.0	0.85	0.50	0.34	1.69
3	131.80	5.88	1.40	0.41	7.69
5	129.30	6.53	4.80	0.71	12.04
7	132.30	1.95	1.55	0.24	3.74
A	142.90	0.31	0.30	0.66	1.26
C	94.75	1.38	0.42	0.63	2.43
E	82.60	6.00	2.51	1.13	9.63
total	809.75	22.89	11.47	4.12	38.48

Total Geological

TABLE B.40: Chitcombe Trench 14 - Quantification of geological material by spit level (kg)

spit	spit weight	large	small	matrix	total
1	96.10	0	0.90	2.06	2.96
3	131.80	0.02	1.10	3.30	4.41
5	129.30	0	1.00	4.83	5.83
7	132.30	0	1.20	1.29	2.49
A	142.90	1.91	0.30	3.33	5.54
C	94.75	0	0.22	2.35	2.57
E	82.60	0.95	0.91	5.27	7.12
total	809.75	2.88	5.62	22.42	30.92

Total Material

TABLE B.41: Chitcombe Trench 14 - Quantification of total analysed material by spit level (kg)

Spit	spit weight	slag	FM	Geo	FR	total
1	96.10	26.24	1.69	2.96	65.29	96.00
3	131.80	56.21	7.69	4.41	63.49	131.80
5	129.30	40.21	12.04	5.83	71.22	129.30
7	132.30	80.60	3.74	2.49	45.47	132.30
A	142.90	96.18	1.26	5.54	39.91	142.90
C	94.75	43.89	2.43	2.57	45.86	94.75
E	82.60	28.21	9.63	7.12	37.63	82.60
total	809.75	371.55	38.48	30.92	368.70	809.75

B.4 Typology

B.4.1 Dominant types

Baked Clay: Clay that has been affected by heat giving it This type is defined by clay that has been affected by heat giving it a variety of colours including yellow, orange, red, grey, green and blue. Textures can vary from soft and friable to very hard.

Corrogated: This type is defined by an upper surface having a corrugated texture. This is defined by a number of tightly packed ridges and can be seen in detail in PICTURE

Flat: This type is defined by the slag being less than 10mm thick and extensive in length and width. This thickness is natural and not formed by fracture.

Fluid Movement Tendril: This type is defined by slag with a upper surface containing tendrils of slag that have flowed in a fluid nature.

Fractured: Formed of a dense slag with low porosity and fractured on 5 or 6 edges with no diagnostic features.

Furnace: mixed conglomeration containing some or all of the following: slag, ore, fm, charcoal, grompy material. Often rough in texture.

Grompy: This type is defined by an orange colour conglomerate that isn't standard slag and can contain ore, charcoal, pieces of slag, potential partly reduced iron and is often magnetic.

Rough Surface: This type is defined by the texture of its upper surface being rough, like course sandpaper

Smooth: This type is defined by having the majority of its upper surface smooth with no features.

Vitrified: complete vitrification of material often being hard dull grey to glassy with colours including green, purple, cream, and black

Images

FIGURE B.15: Chitcombe Baked clay

FIGURE B.16: Chitcombe Corrogated

FIGURE B.17: Chitcombe Fluid Movement Tendril

FIGURE B.18: Chitcombe Fractured

FIGURE B.19: Chitcombe Smooth

FIGURE B.20: Chitcombe Flat

FIGURE B.21: Chitcombe Rough surface

FIGURE B.22: Chitcombe Grompy

FIGURE B.23: Chitcombe Vitrified

B.4.2 Non-dominant types

Amorphous: no identifiable features and does not fit any other type

Amorphous Cake: This type is defined by its shape. It has a relatively flat upper surface and a convex lower surface with fractured edges showing it formed part of a larger slag that would have formed in a depression.

Amorphous Furnace: rough texture slag with no obvious edges or fractures and inclusions of furnace material

Amorphous ore surface: no defining features but ore inclusions on all non-fractured edges

Amorphous Possible imprint: This type is defined by the fact that it has no diagnostic features but may have formed around something.

Crystaline surface: This type is defined by an upper surface having visible crystalline structure – often where a frature may have occurred or within a very large porosity

Dull Porous: slag with large percentage of porosity and possible fluid movement being a dull grey colour compared to other slag samples

Flat with Ore: This type is defined by the slag being less than 10mm thick and extensive in length and width. This thickness is natural and not formed by fracture. A large amount of ore fragments are imbedded in the sample.

Fluid Tendril Furnace: slag formed of tendrils with no obvious orientation and areas of open texture

Fractured Large Porosity Surface: Single surface (usually upper) with large fractured porosity above 20mm

Fractured Porous: fractured surface with high porosity and no other identifying features

Furnace lining: hard/vitrified, unique form, different to 'standard' furnace material.

Furnace Mixture: This type is defined by its rough conglomeration of small slag, charcoal, possible wood with no real form (CINDERS???)

Grompy Adhesions: This type is defined by undiagnostic pieces of 'normal' slag with patched of grumpy material adhered a surface

Messy Porous Surface: large amount of fractured porosity on surface with a messy texture, like messy ripple.

Messy Ripple: This type is defined by having an upper surface that shows a mixture of textures including porosity, ripples, corrugation and messy ripple This type is defined by the texture of its upper surface. This texture has a number of ridges formed in various directions.

Ore: geological material which is purple/red in colour and dusty to touch

Porous Surface: The type is defined as being a piece of slag with a large amount of porosity on a single edge only.

Slag with Ore: This type is defined by a piece of slag with large pieces of ore set within it.

Smooth Fluid Movement: large flat tendrils with a smooth surface

Unobvious Fluid Movement: partial formed tendrils with no orientation but not evidently FMT or furnace slag

Very Large Fractured Porosity: fractured porosity on surface >100mm

B.5 Classification

Spit 1

Spit One contains 238 individual samples covering 16 types. The three most common types by weight will be set out in brief below

TABLE B.42: Classification of top 3 dominant types by weight, Spit 1

Type	FMT	Corrogated	Fractured
Material	Slag	Slag	Slag
Weight(g)	4300	4000	2180
Number	61	64	32
Min/max size	3.2x2.4 / 6.7x5.4	2x2.5 / 7.2x4.1	2.8x2.7 / 8.2x6.1
Shape	Amorphous	Amorphous	Amorphous
Fracture	3-5	3-5	5-6
Porosity shape	Elongated	Spherical	Spherical
Porosity size (mm)	1-35	1-6	1-10
Porosity %	<5	<5	<5
Inclusions	FM/ore	FM/ore	ore
Vitrification	NA	NA	NA

Spit 3

Spit three contains 444 individual samples covering 21 types. The three most common types by weight will be set out in brief below

Spit 5

Spit five contains 402 individual samples covering 16 types. The three most common types by weight will be set out in brief below

TABLE B.43: Classification of top 3 dominant types by weight, Spit 3

Type	FMT	Corrogated	Rough Surface
Material	Slag	Slag	Slag
Weight(g)	13700	7200	6000
Number	174	109	24
Min/max size	2.8x2.9 / 8x8.7	2.5x2.4 / 10.4x5.5	3.1x2.4 / 18.5x16
Shape	mix plano	amorphous	plano
Fracture	3-5	3-5	4-5
Porosity shape	mix	unclear	unclear
Porosity size (mm)	1-20	unclear	unclear
Porosity %	<5	unclear	unclear
Inclusions	FM/ore	FM/ore	FM/ore
Vitrification	NA	NA	NA

TABLE B.44: Classification of top 3 dominant types by weight, Spit 5

Type	FMT	Corrogated	Vitrified
Material	slag	slag	FM
Weight(g)	11500	7900	4600
Number	113	105	40
Min/max size	3.4x2.2 / 10.6x7	2.8x2.5 /9.2x6	3.5x2/11x8
Shape	amorphous	amorphous	amorphous
Fracture	3-5	3-5	5-6
Porosity shape	mix	spherical	NA
Porosity size (mm)	1-8	1-27	NA
Porosity %	<10	<10	NA
Inclusions	FM/ore	FM/ore	none
Vitrification	NA	NA	complete

Spit 7

Spit seven contains 752 individual samples covering 14 types. The three most common types by weight will be set out in brief below

TABLE B.45: Classification of top 3 dominant types by weight, Spit 7

Type	FMT	Corrogated	Fractured
Material	slag	slag	slag
Weight(g)	24700	14900	2390
Number	296	208	56
Min/max size	3.5x2 / 13.7x7.8	3.1x2.6 / 8.5x4.6	3x2.5 7.3x4.5
Shape	amorphous	amorphous	amorphous
Fracture	3-5	3-5	5
Porosity shape	irregular/spherical	irregular/spherical	spherical
Porosity size (mm)	1-60	1-40	1-14
Porosity %	<10	<5	<5
Inclusions	FM/ore	FM/ore	ore
Vitrification	NA	NA	NA

Spit A

Spit A contains 574 individual samples covering 12 types. The three most common types by weight will be set out in brief below

TABLE B.46: Classification of top 3 dominant types by weight, Spit A

Type	FMT	Corrogated	Fracture
Material	slag	slag	slag
Weight(g)	54000	9500	3000
Number	302	157	54
Min/max size	3.2x3.5 / 22.5x18	2.5x2 / 7.5x5.9	3x2.5 / 6.5x4.3
Shape	amorphous	amorphous	amorphous
Fracture	3-5	4	5
Porosity shape	mix	mix	mix
Porosity size (mm)	1-13	1-30	1-15
Porosity %	<5	<5	<10
Inclusions	FM/ore	FM/ore	FM/ore
Vitrification	NA	NA	NA

Spit C

Spit C contains 314 individual samples covering 9 types. The three most common types by weight will be set out in brief below

TABLE B.47: Classification of top 3 dominant types by weight, Spit C

Type	FMT	Fracture	Grompy
Material	slag	slag	slag
Weight(g)	6900	2400	2200
Number	92	47	39
Min/max size	2.5x3.5 / 7.5x7.5	3x2.5 / 5x5	2.5x3 / 14x9
Shape	amorphous	amorphous	amorphous
Fracture	3-5	unclear	unclear
Porosity shape	unclear	mix	mix
Porosity size (mm)	1-18	1-7	unclear
Porosity %	<10	<5	unclear
Inclusions	FM/ore	ore	FM/ore/charcoal
Vitrification	NA	NA	NA

Spit E

Spit E contains 290 individual samples covering 8 types. The three most common types by weight will be set out in brief below

TABLE B.48: Classification of top 3 dominant types by weight, Spit E

Type	Grompy	Baked Clay	Fracture
Material	slag	FM	slag
Weight(g)	7300	6000	4800
Number	65	119	36
Min/max size	3x3 / 22x17	2.5x2.5 / 18.5x13	2.5x2.7 / 8x11
Shape	amorphous	amorphous	amorphous
Fracture	unclear	4-6	5-6
Porosity shape	unclear	NA	mix
Porosity size (mm)	unclear	NA	1-20
Porosity %	unclear	NA	30
Inclusions	FM/ore/charcoal	none	FM
Vitrification	NA	rare	NA

C Case Study 2 - Standen - Geo-prospection

C.1 Raw Data Images

C.1.1 Magnetometry

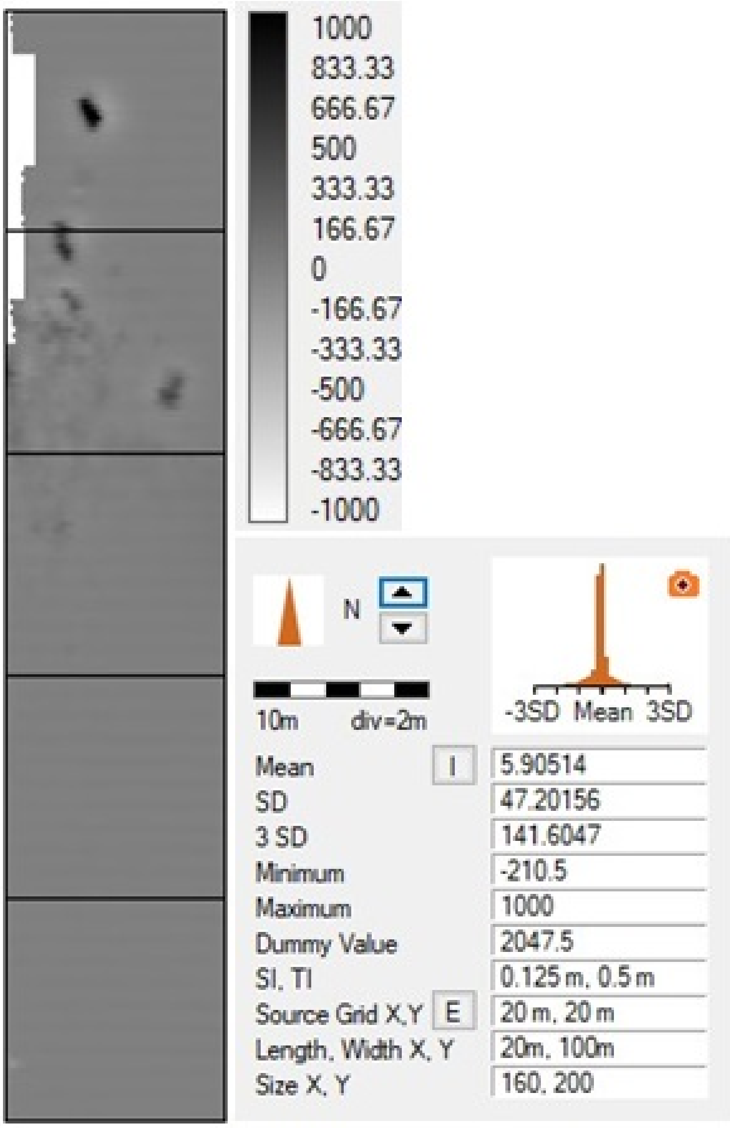

FIGURE C.1: Magnetometry Field raw data

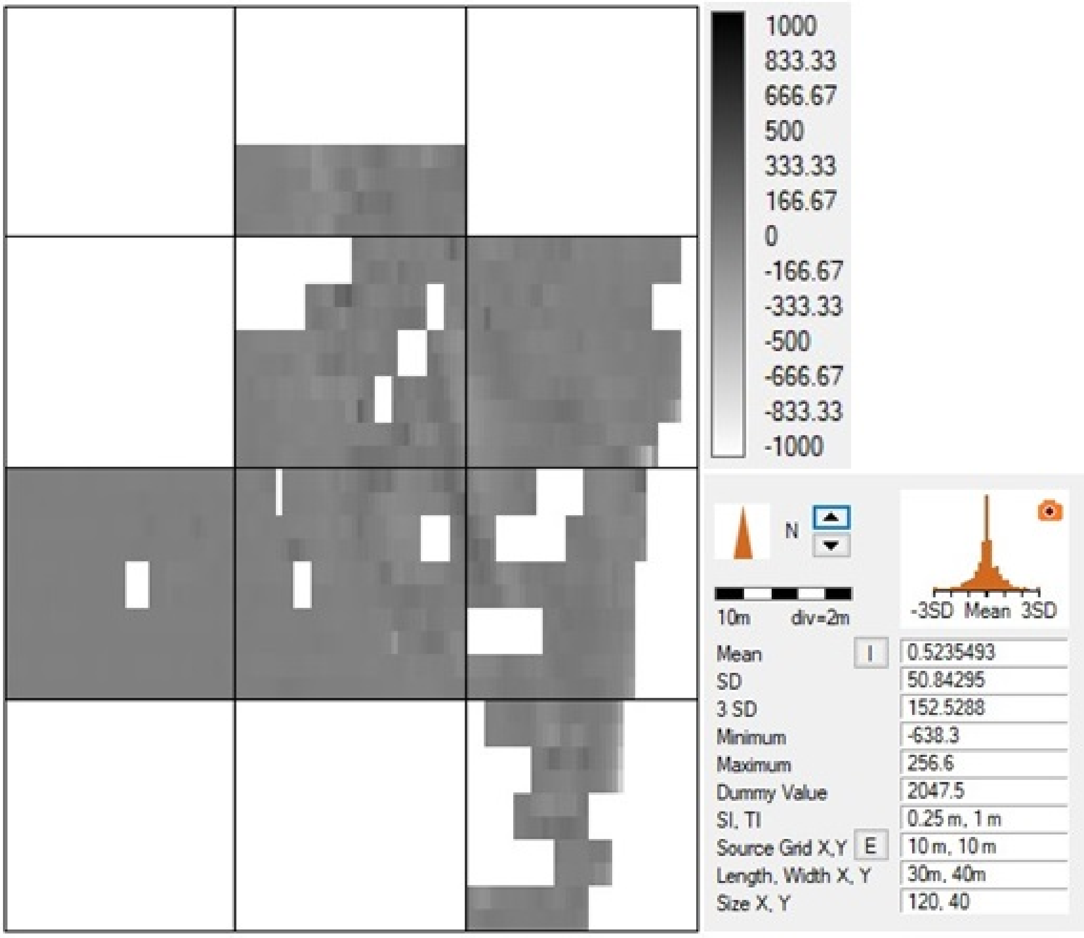

FIGURE C.2: Magnetometry Field raw data

C.1.2 Earth Resistivity Tomography

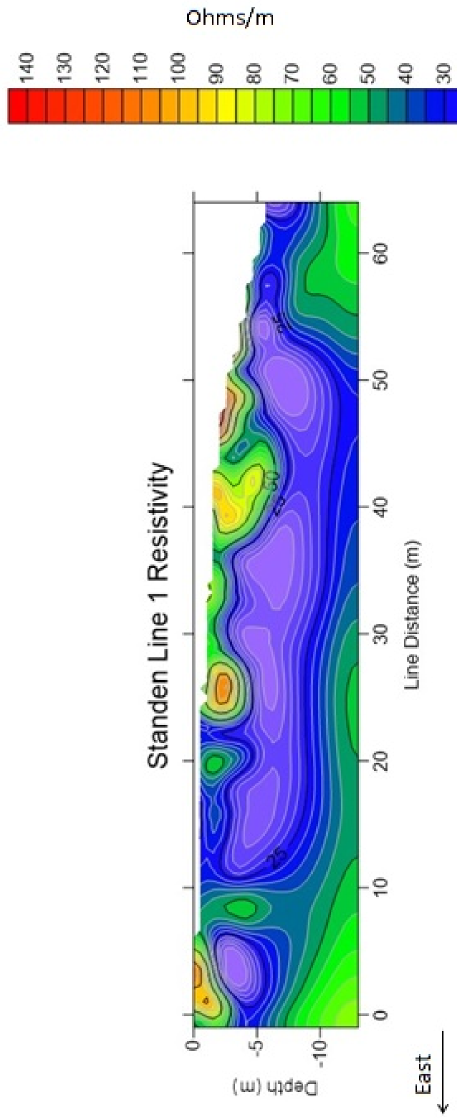

FIGURE C.3: Earth Resistivity Tomography Line 1 Raw Data

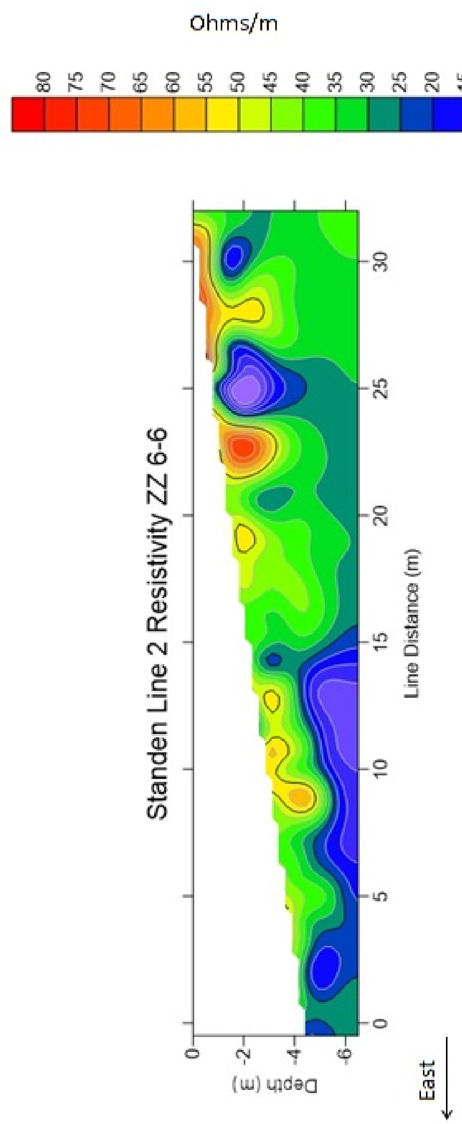

FIGURE C.4: Earth Resistivity Tomography Line 2 Raw Data

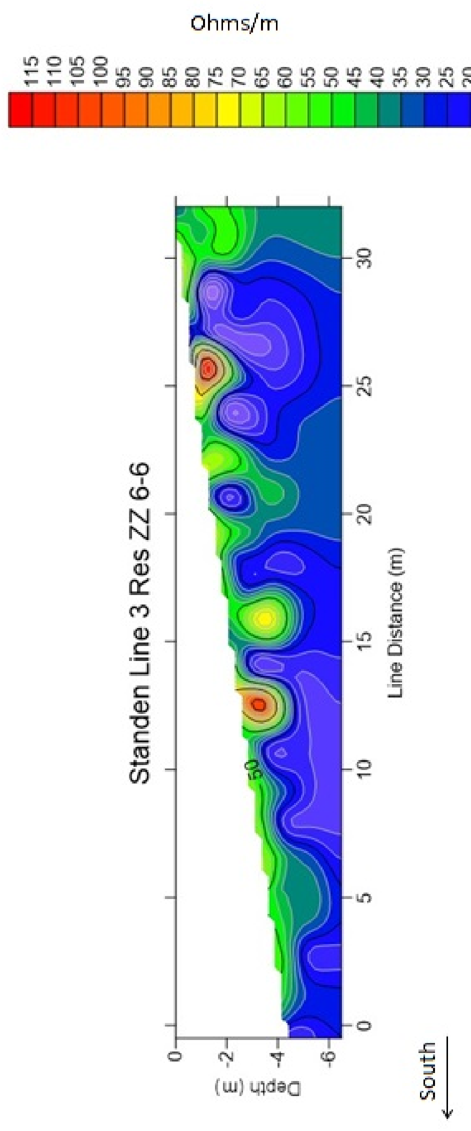

FIGURE C.5: Earth Resistivity Tomography Line 3 Raw Data

C.1.3 Induced Polarisation

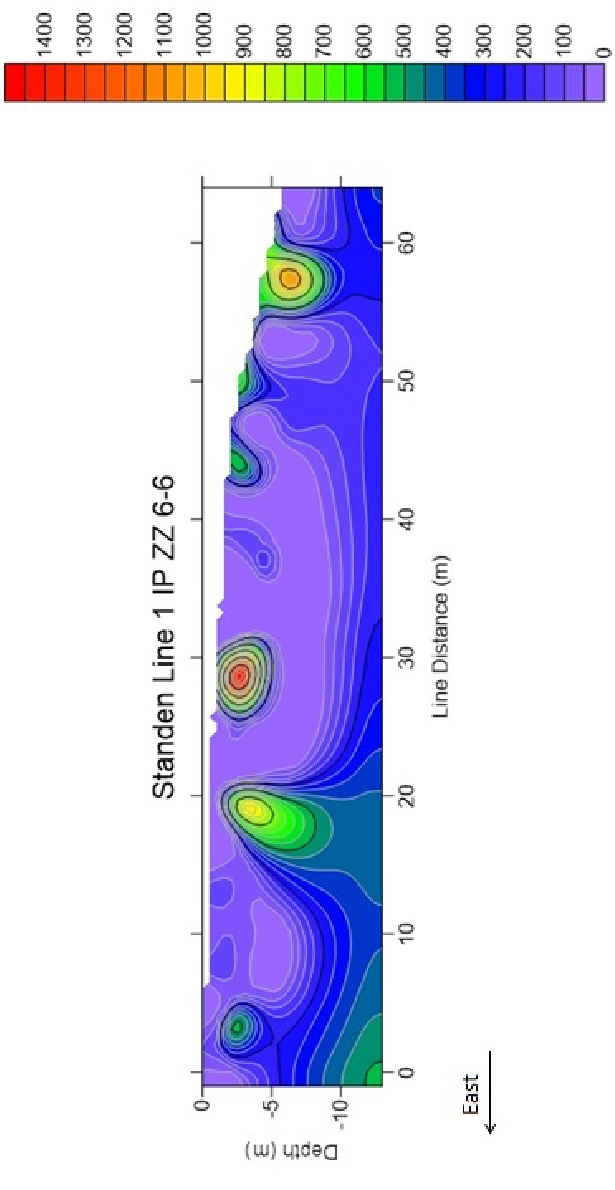

FIGURE C.6: Induced Polarisation Line 1 Raw Data

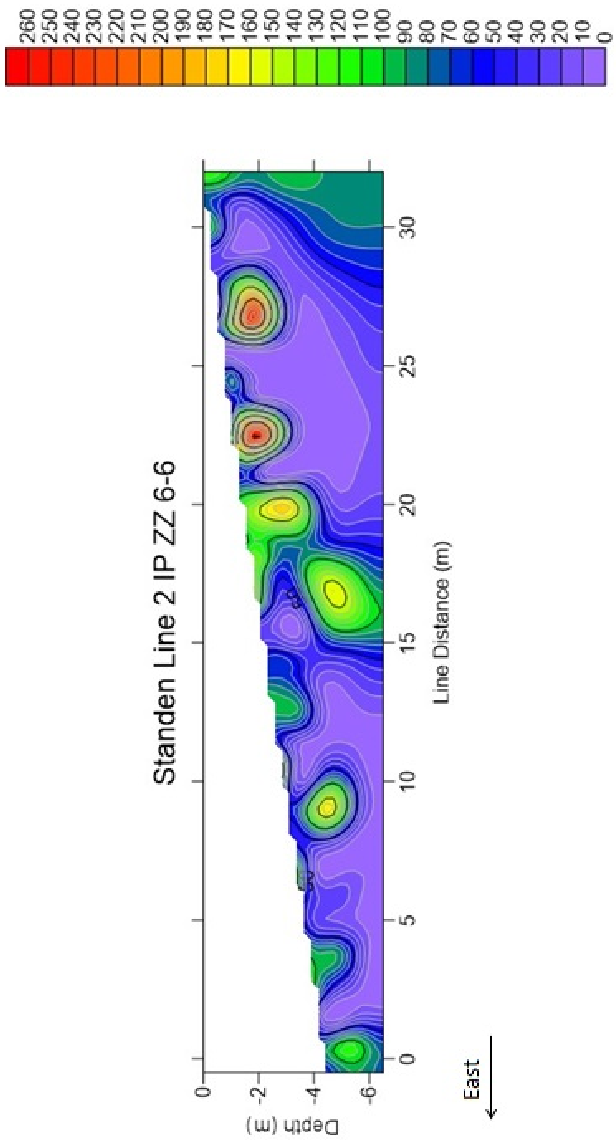

FIGURE C.7: Induced Polarisation Line 2 Raw Data

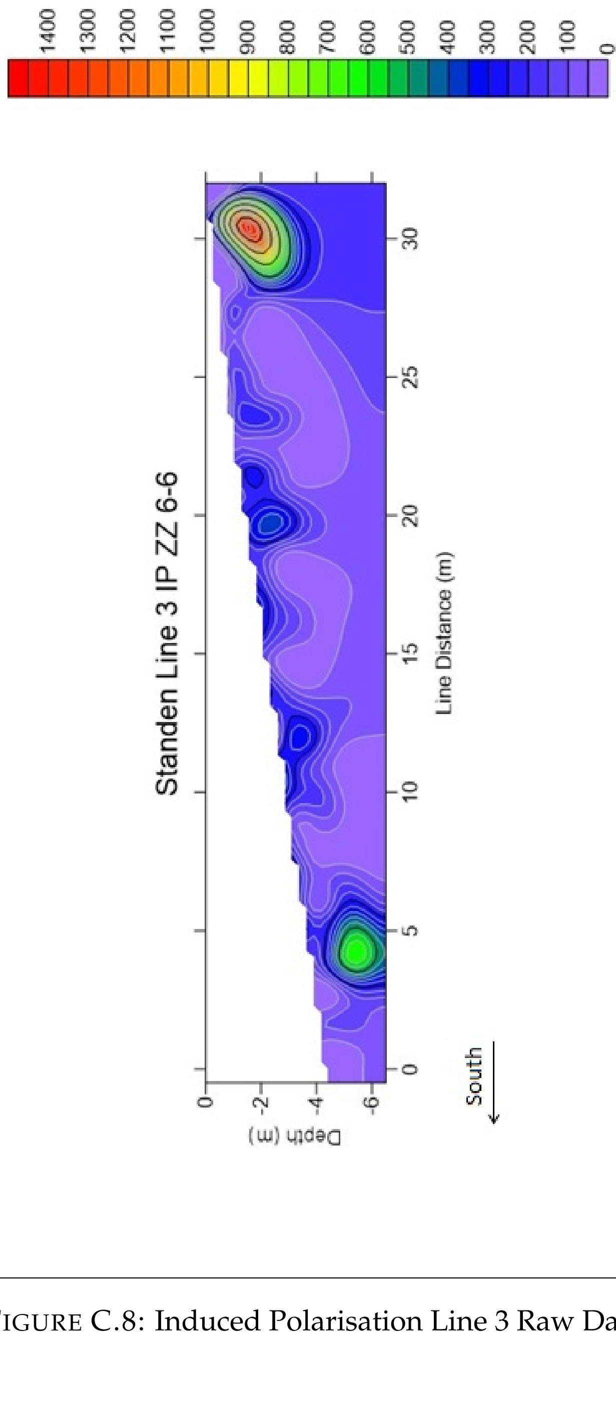

FIGURE C.8: Induced Polarisation Line 3 Raw Data

C.1.4 Electromagnetic

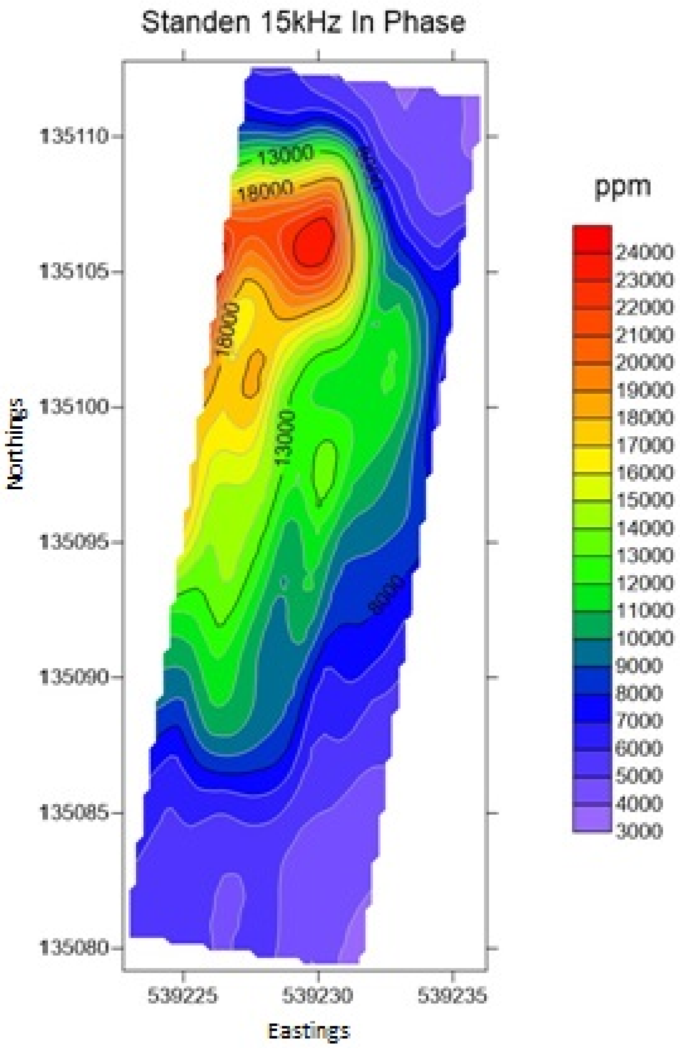

FIGURE C.9: In-phase 15kHz

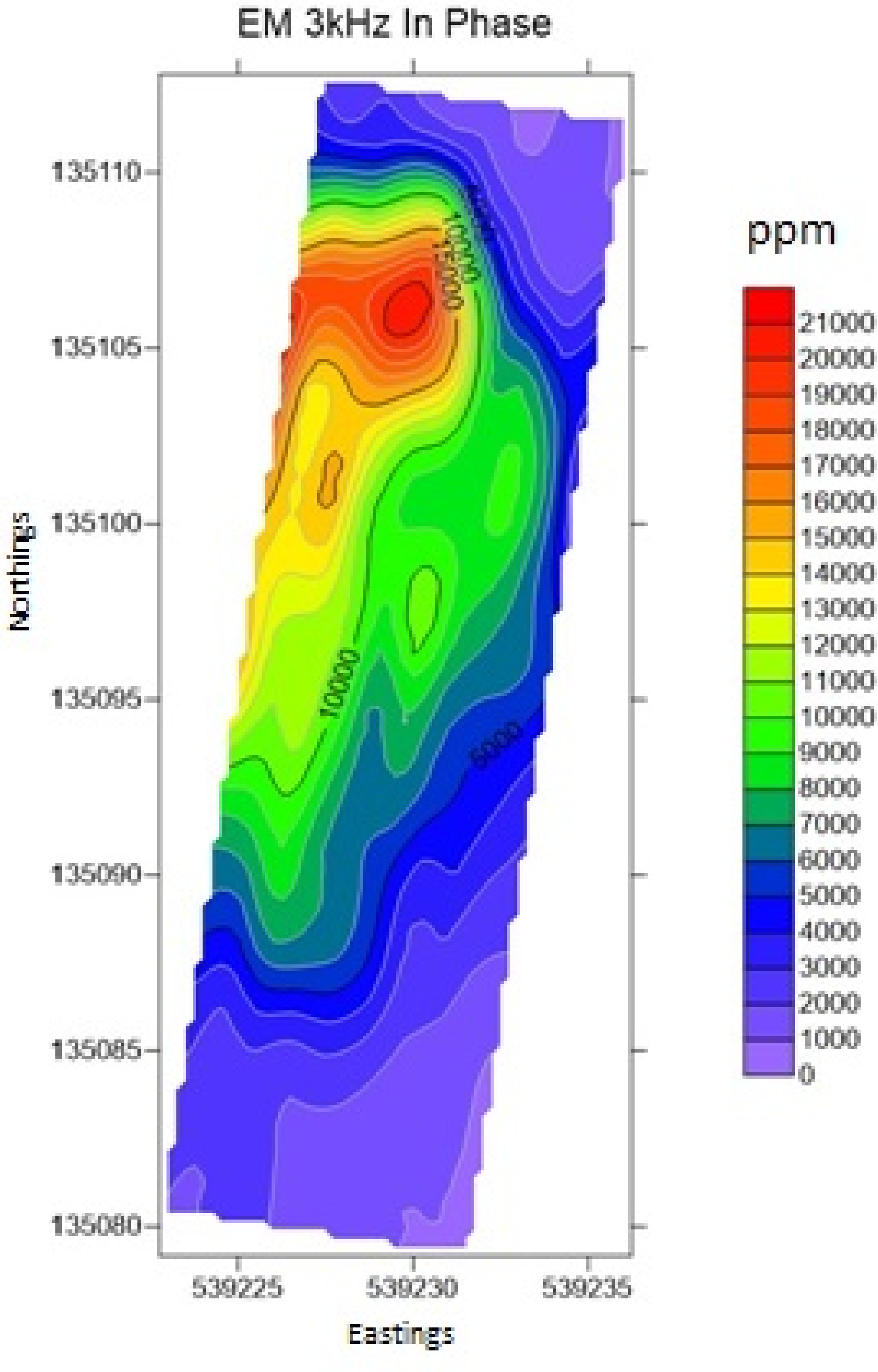

FIGURE C.10: In-phase 3kHz

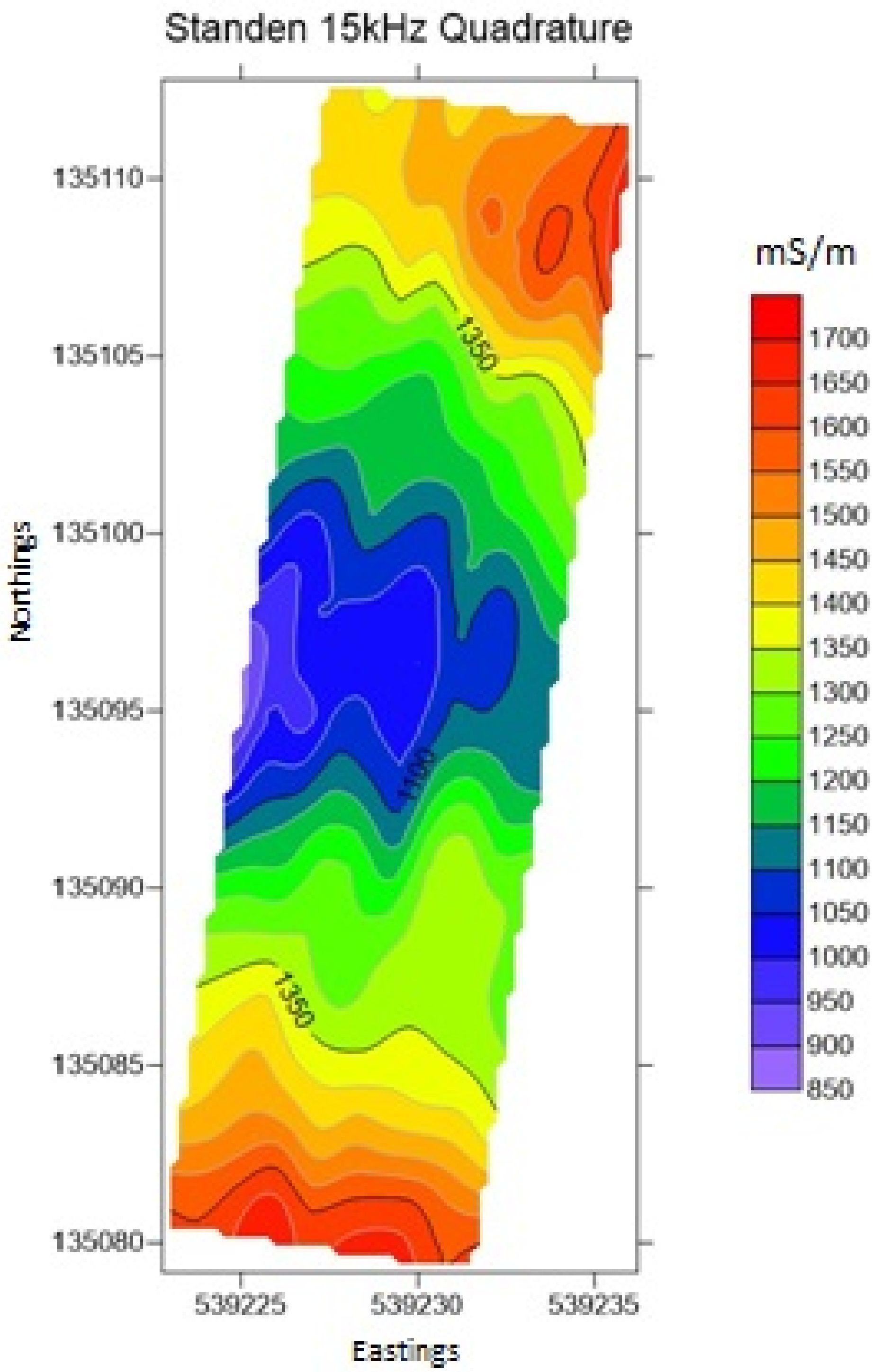

FIGURE C.11: Quadrature 15kHz

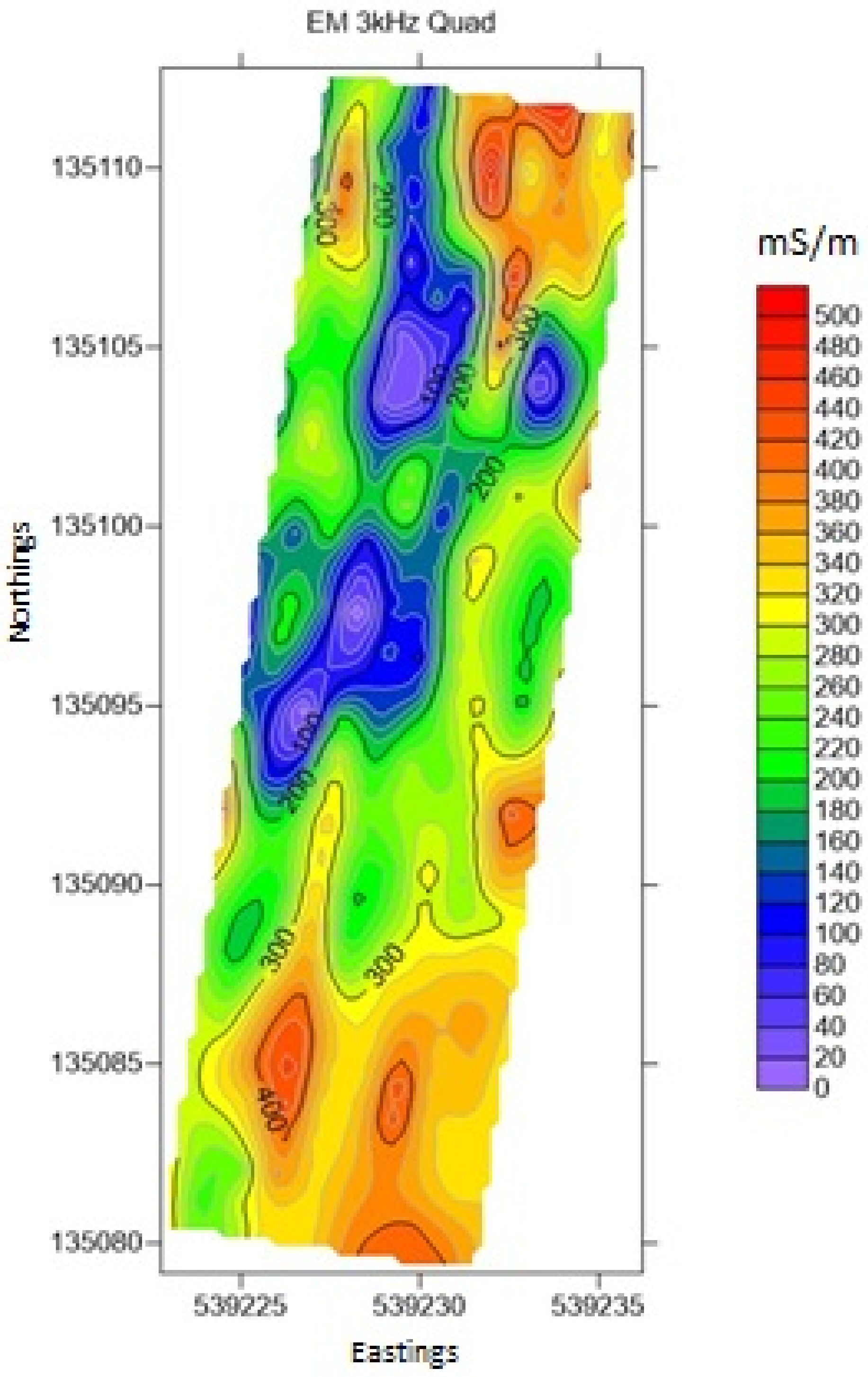

FIGURE C.12: Quadrature 3kHz

C.2 Annotated Images and Discussion

C.2.1 Magnetometry

Field

Anomalies:

Furnace (RED) Three circular high magnetic anomalies with readings up to 1000nT.

Secondary deposition (Dark Blue) Interpreted as a working area between the furnaces with readings up to 300nT

Other observations:

- The halo of increased magnetism in the north-east of the survey is from a large pylon.

Associations:

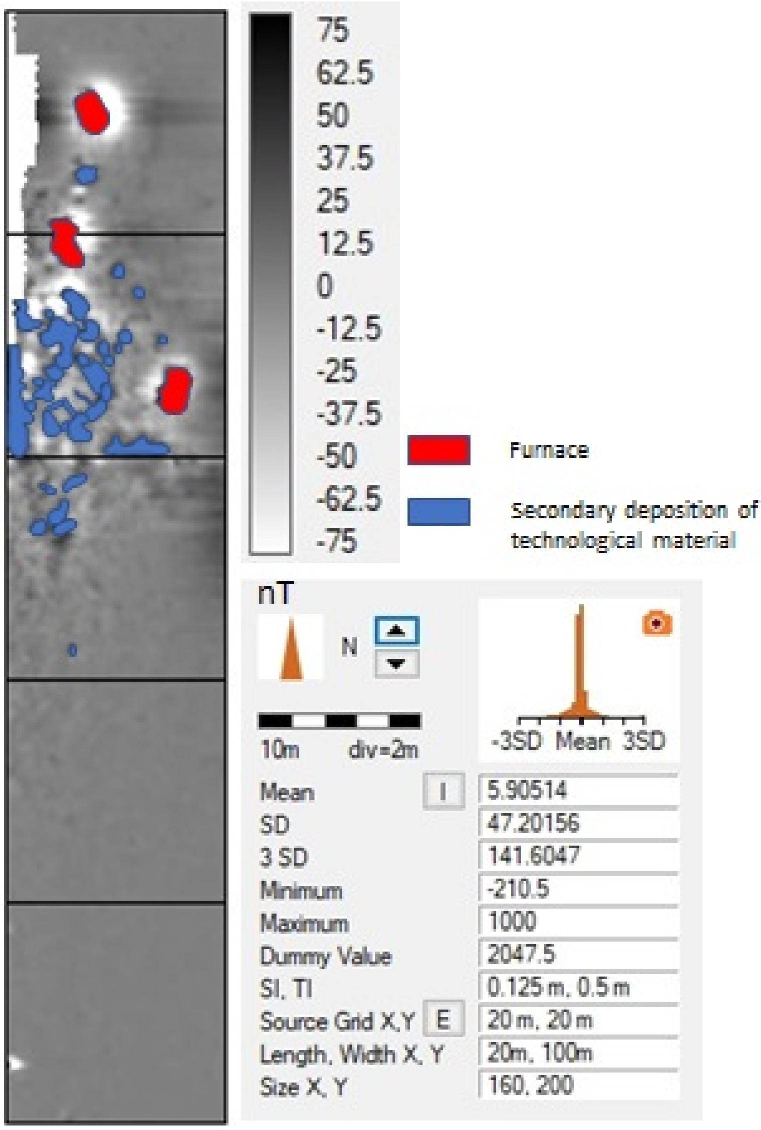

FIGURE C.13: Magnetometry Field Normalised and Annotated Data

Woodland

Anomalies:

Primary deposition (Light blue) The linear anomaly that sits on the eastern edge of the area of primary deposit is the old field boundary. This and everything to the west, down the hill, is believed to have been unaffected by ploughing.

Secondary deposition (Dark Blue) interpreted as the response from technological material but heavily effected by ploughing

Other observations:

Associations:

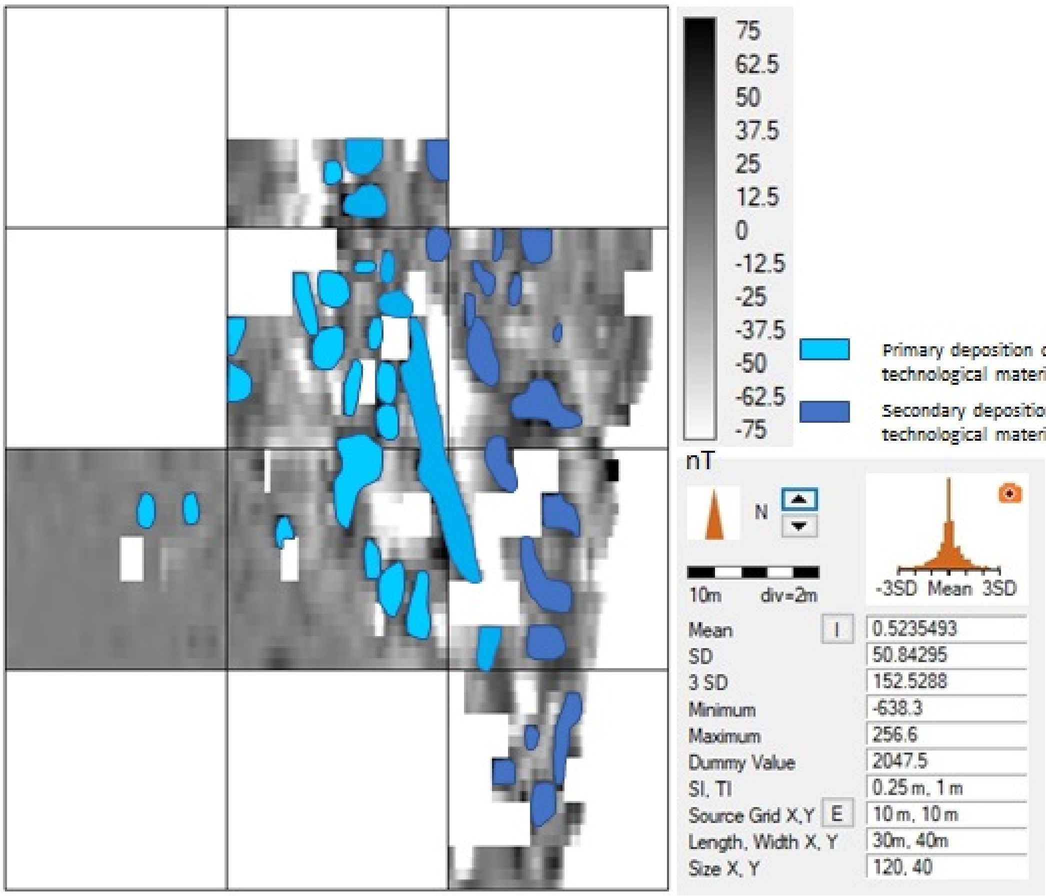

FIGURE C.14: Magnetometry Wood Normalised and Annotated Data

C.2.2 Earth Resistivity Tomography

ST-ERT-1

Anomalies:

0-6m lat: UAD (dark blue) Increased resistivity anomaly on the ground surface measuring 100 Ohms representing a deposit of technological waste most likely forming a working area.

15-35 lat: UAD (dark blue) could represent working area of ploughed TWD

35-50m lat: TWD (light blue) Area of mixed increase resistivity along the ground surface with highest readings of 140 Ohms.

Other observations:

-Large areas of the survey, particularly in the lower areas, have readings of below 20 Ohms and represents the natural clay geology.

Associations:

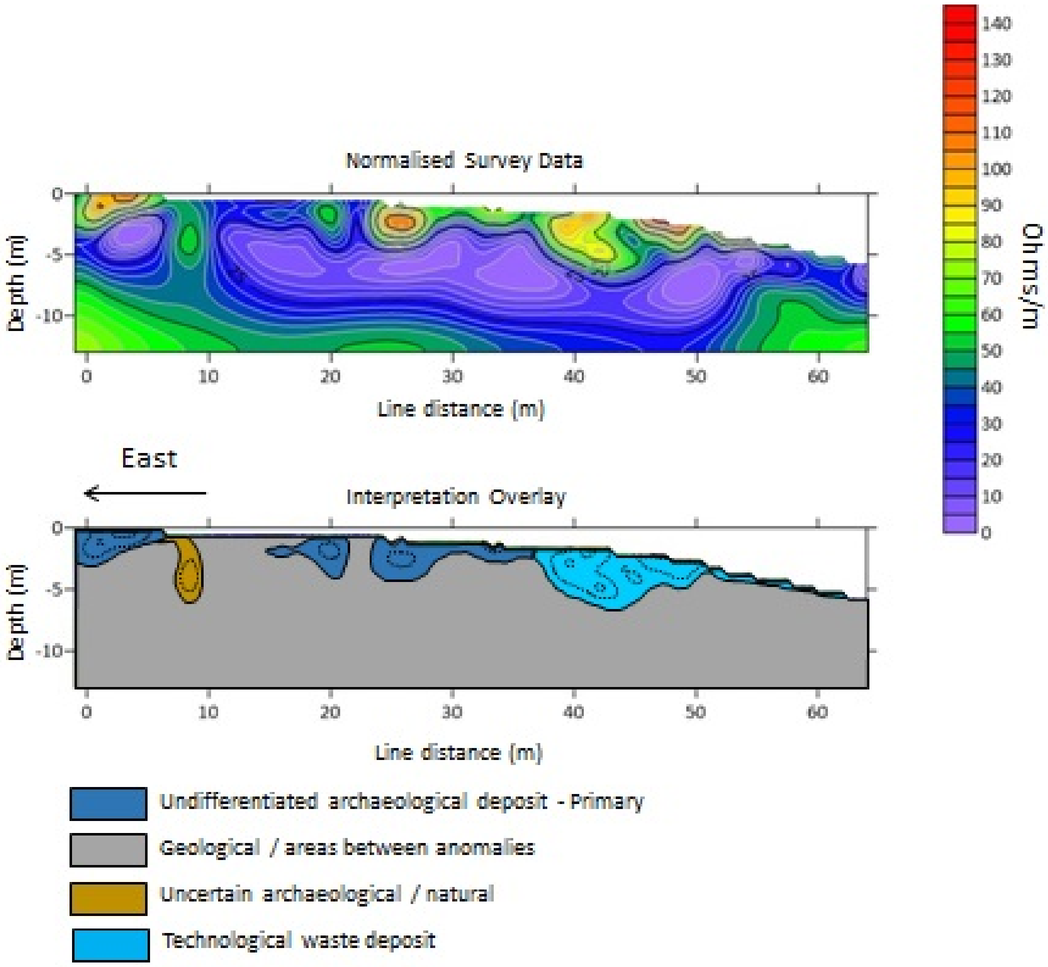

FIGURE C.15: Earth Resistivity Tomography Line 1 Normalised and Annotated Data

ST-ERT-2

Anomalies:

28m Lat: possible post hole or pit feature below a spread of similar increased resistivity measuring 70 Ohms which could represent part of the working area.

Other observations:

-A number of other anomalies along the ground surface measuring between 50-80 Ohms could represent deposits of technological waste material.

Associations:

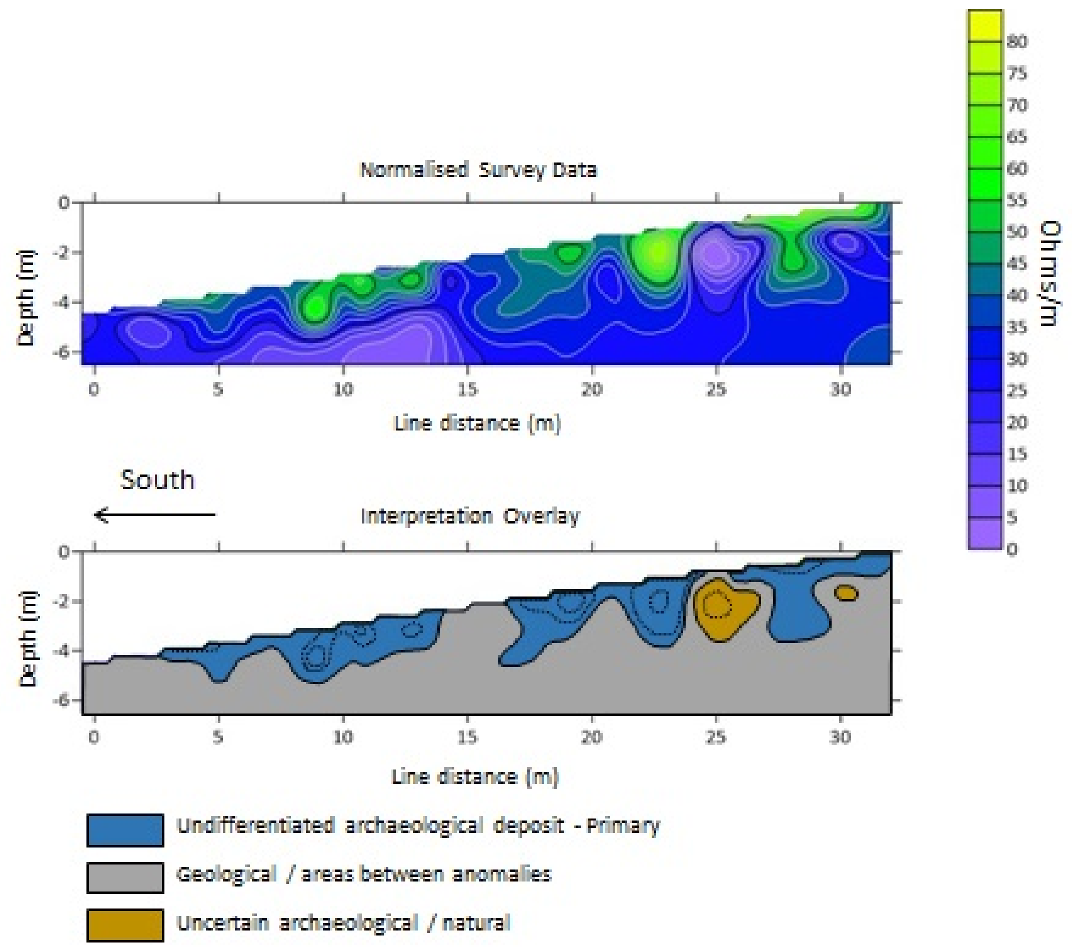

FIGURE C.16: Earth Resistivity Tomography Line 2 Normalised and Annotated Data

ST-ERT-3

Anomalies:

0-13m lat: A thin spread of increased resistivity measuring between 50-70 Ohms between 0-11m along the ground surface with an anomaly measuring up to 105 Ohms on its northern end at 12.5m. This could represent a concentrating of material due to more modern ploughing of the field along the ground surface or represent a working surface with a feature at its norther end.

18-23m lat: A low resistivity anomaly measuring 10 Ohms surrounded by increased resistivity measuring up to 65 Ohms. Could represent a structure associated with iron production.

29-32m lat: A feature consisting of increased resistivity on base and top with a lower resistivity centre. Could represent a structure associated with iron production.

Other observations:

- A number of increased resistivity anomalies along the ground surface measuring between 50-115 Ohms most likely represent deposits of technological waste.

Associations:

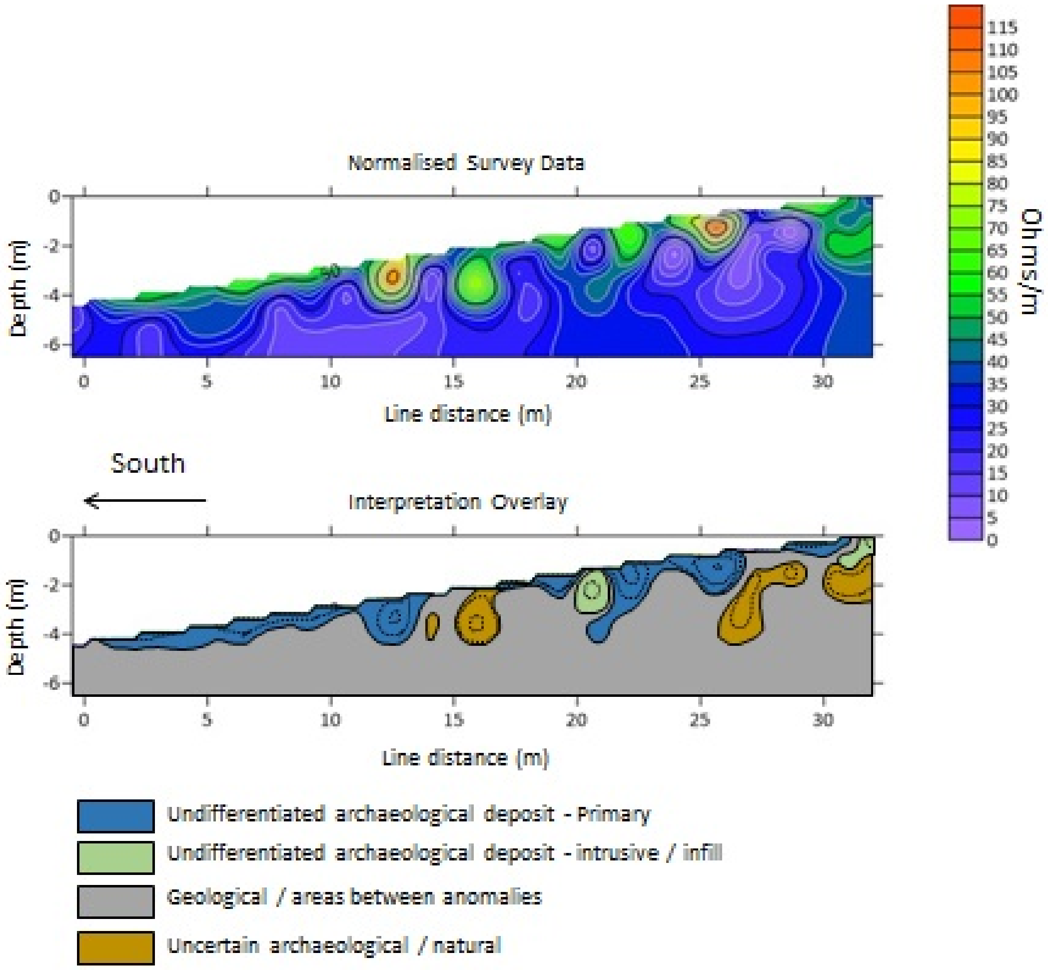

FIGURE C.17: Earth Resistivity Tomography Line 3 Normalised and Annotated Data

C.2.3 Induced Polarisation

ST-IP-1

Anomalies:

35-60m: TWD (light blue) A number of anomalies along the ground surface measuring up to 1400 are interpreted as the response from the technological waste deposit.

Other observations:

-wide range in response from technological waste deposit showing the material causing the increased reading is in specific deposits.

Associations:

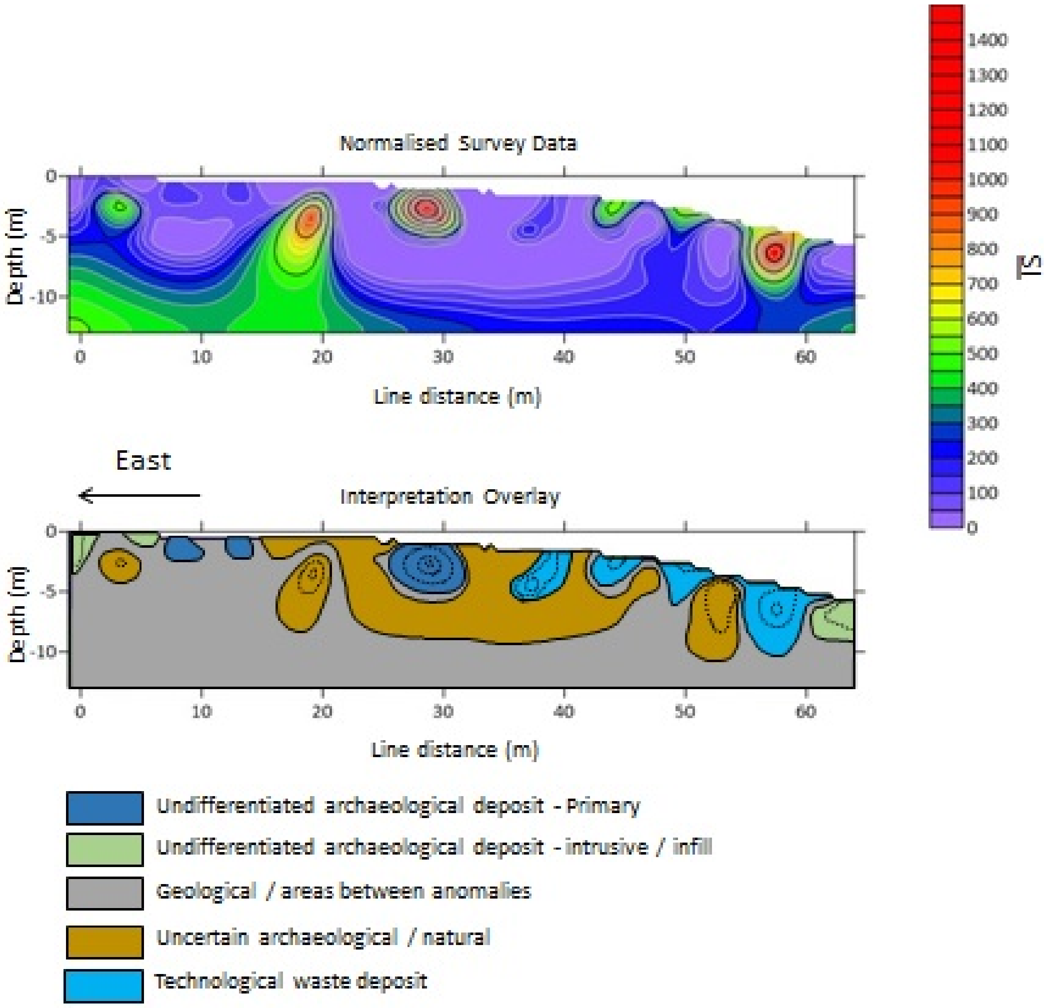

FIGURE C.18: Induced Polarisation Line 1 Normalised and Annotated Data

ST-IP-2

Anomalies:

General spread of UAD

Other observations:

-The majority of anomalies in this survey are of relatively low resistivity. They are positioned along the ground surface and could therefore been seen as representing non-natural deposits but with no clear interpretation.

Associations:

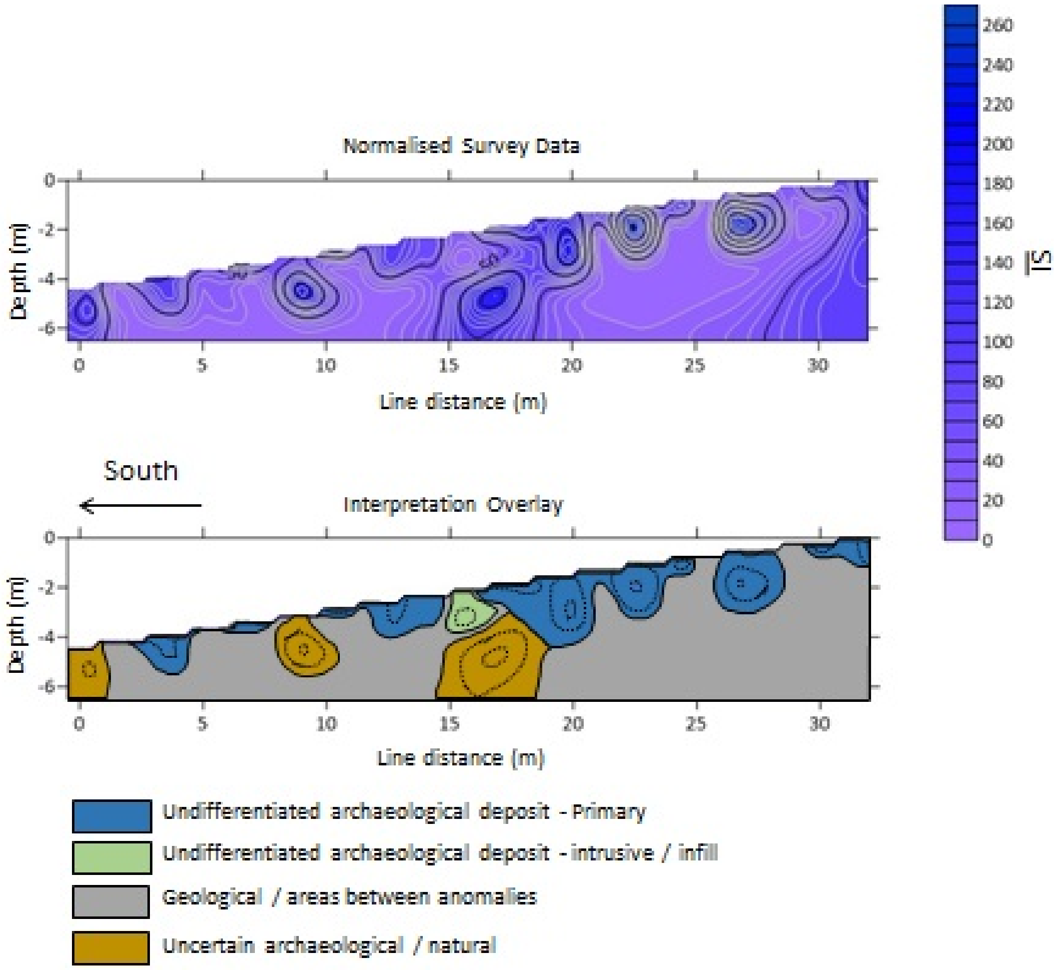

FIGURE C.19: Induced Polarisation Line 2 Normalised and Annotated Data

ST-IP-3

Anomalies:

20m lat: An anomaly measuring up to 400 is in the position of a structure associated with iron production according to the ERT survey.

30m lat: An anomaly measuring up to 1400 is in the position of a structure associated with iron production according to the ERT survey.

Other observations:

- An anomaly between 10-14m is in the position of an increased resistivity response as part of a possible ground surface a large deposit.

- Centred on 4m is an anomaly measuring 650. It is below the ground surface and is unclear if it is natural or archaeological. However it is positioned just under a spread of increased resistivity anomalies.

Associations:

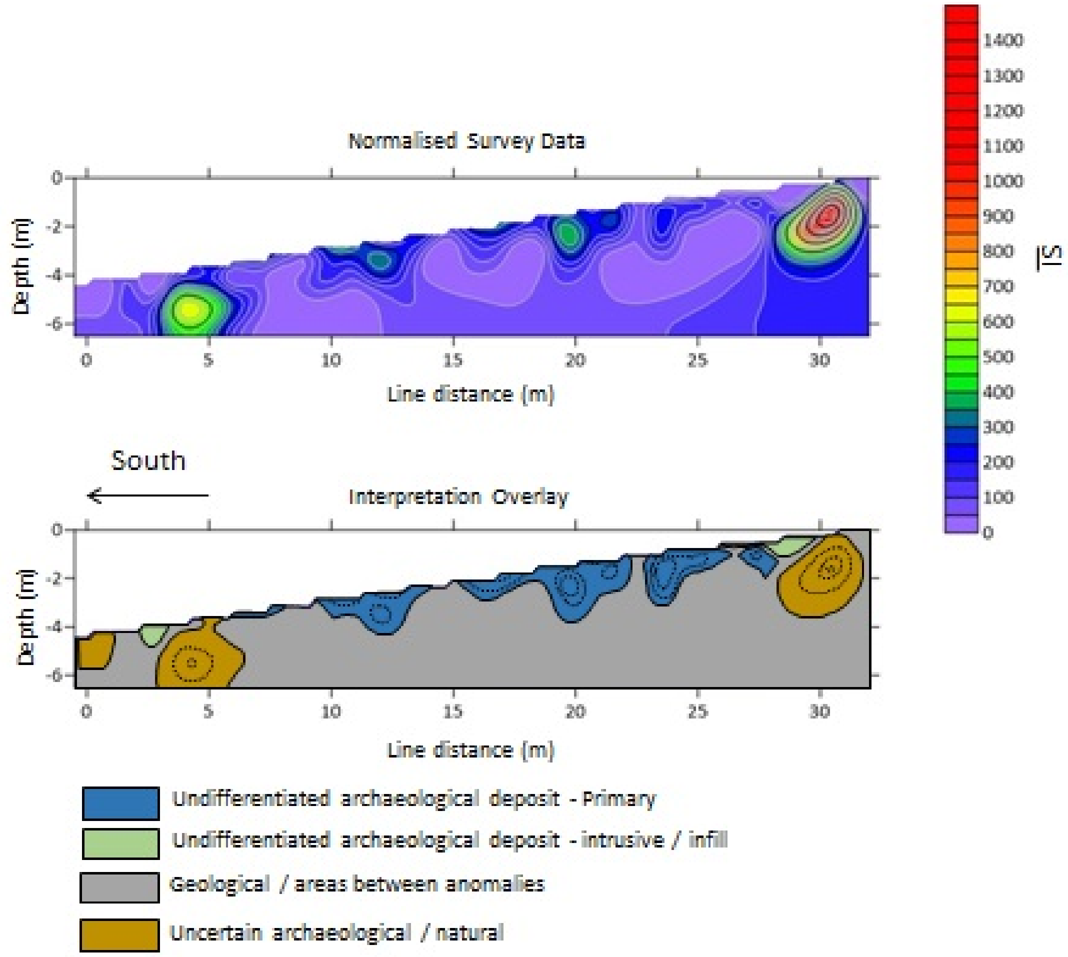

FIGURE C.20: Induced Polarisation Line 3 Normalised and Annotated Data

C.2.4 Electromagnetic

In-phase

Field-IN-15K

Anomalies:

(A) 539230E,135100N: A larger area of increases magnetic susceptibility interpreted as a working area. The highest reading is in an anomaly at 539230E,135107N and has readings of 24000ppm.

Other observations:

- Areas in the north-east and south-east corners of the trench measuring 3000ppm are believed to represent the natural geology.

Associations:

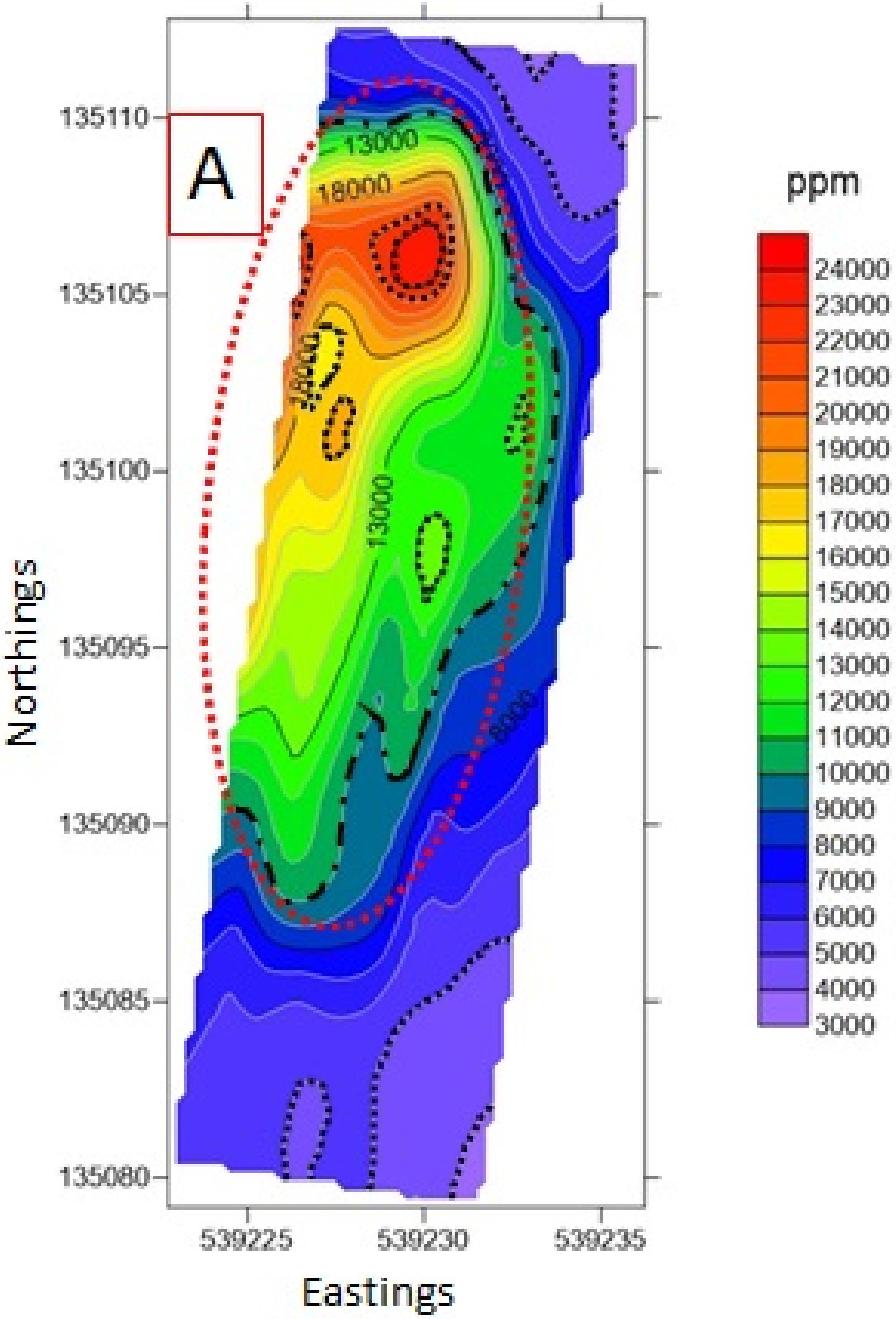

FIGURE C.21: In-phase 15kHz Normalised and Annotated

Field-IN-3K

Anomalies:

(A) 539230E,135100N: A larger area of increases magnetic susceptibility interpreted as a working area. The highest reading is in an anomaly at 539230E,135107N and has readings of 21000ppm.

Other observations:

- Areas in the north-east and south-east corners of the trench measuring 3000ppm are believed to represent the natural geology.

Associations:

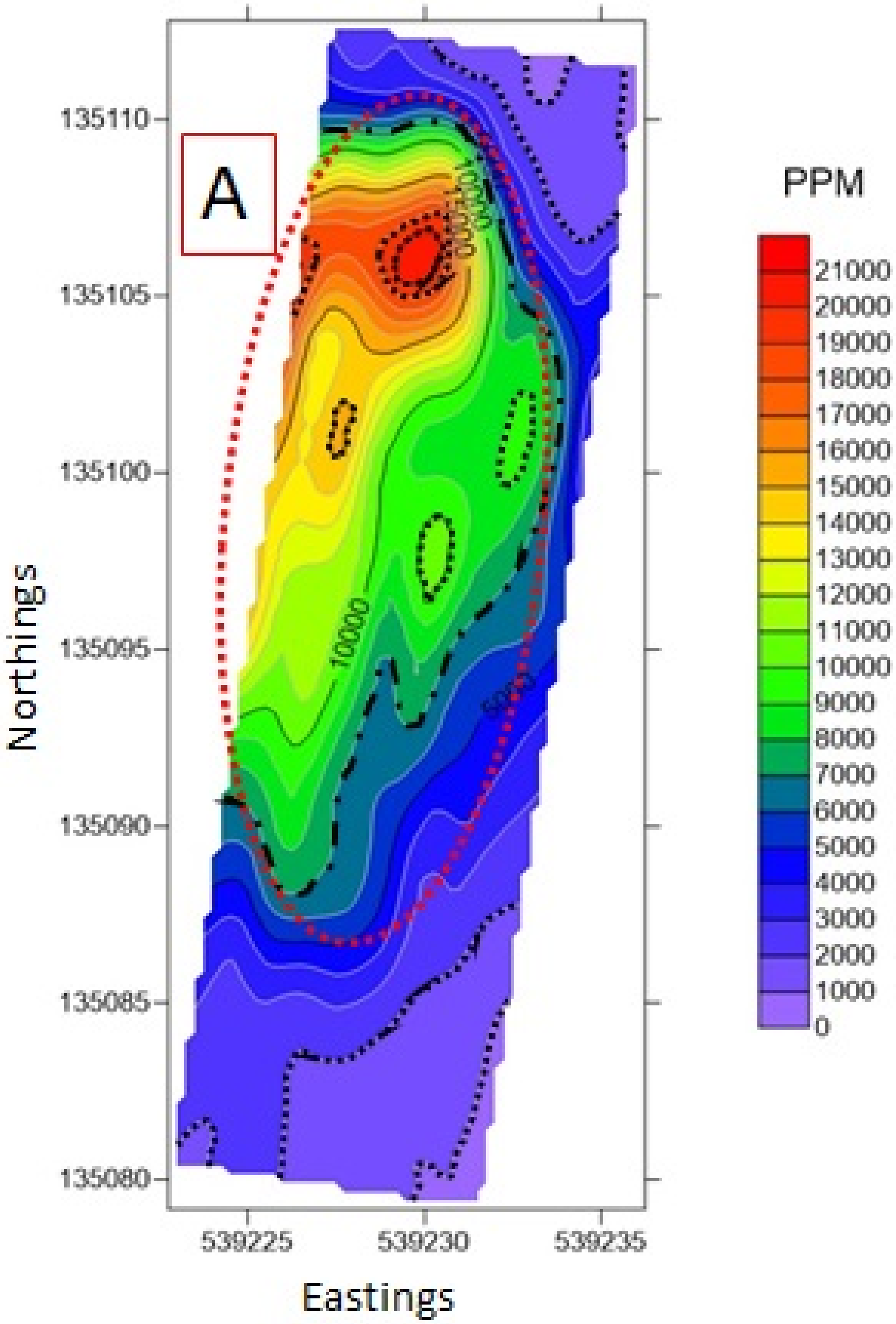

FIGURE C.22: In-phase 3kHz Normalised and Annotated

Quadrature

Field-Q-15K

Anomalies:

(A) 539239E,135097N: An area of low conductivity with the lowest area measuring 850 ppm at 539225E,135096N. The readings increase in all directions from this point. This is interpreted as the response from a working area.

Other observations:

- The highest areas measuring up to 1700 ppm are in the north-east and south-east corners and can be interpreted as the response from the natural geology.

Associations:

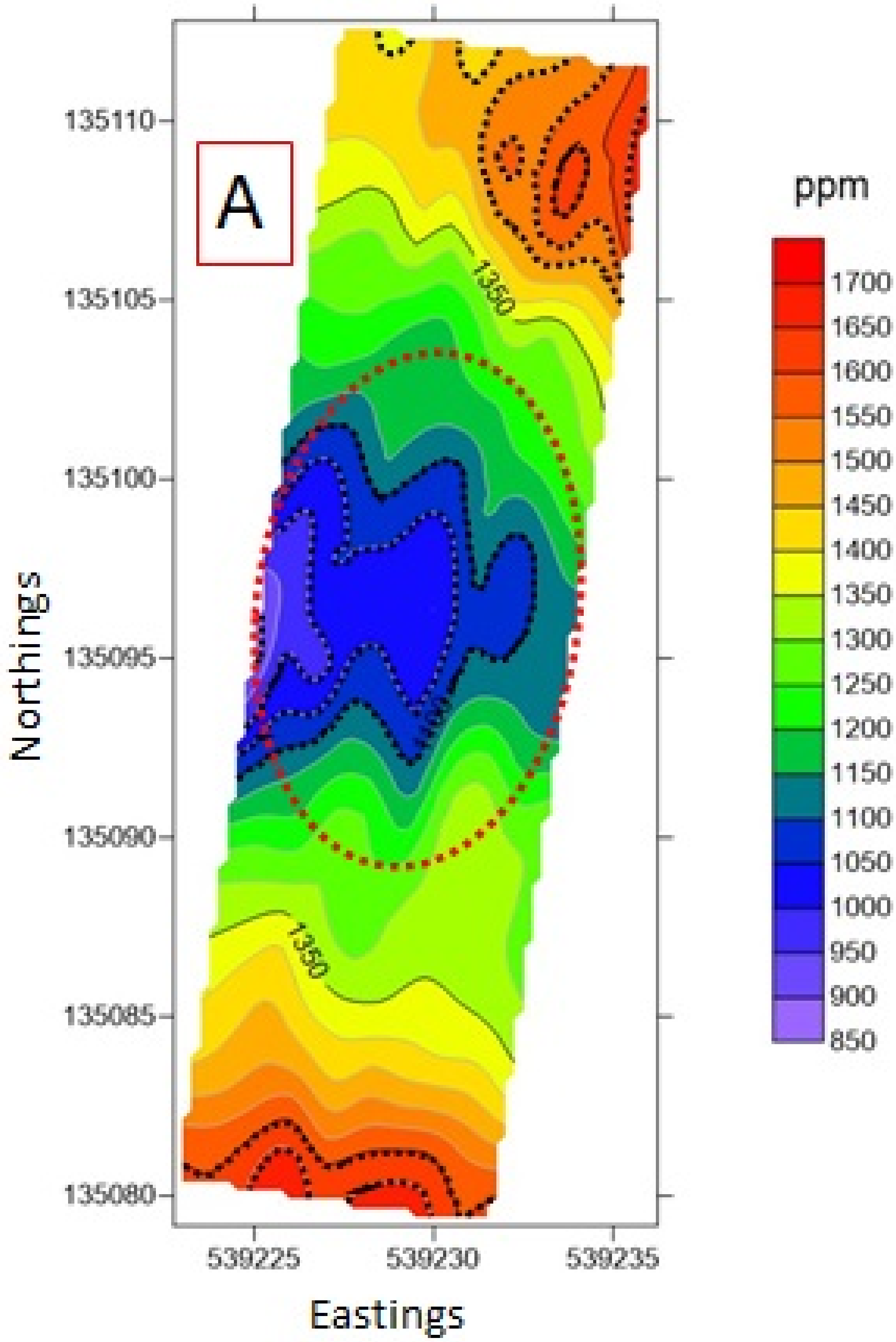

FIGURE C.23: Quadrature 15kHz Normalised and Annotated

Field-Q-3k

Anomalies:

(A) 539228E,135100N: An area of decreased mixed conductivity. The main low areas measure between 0-200 ppm and form a slightly curved line. This whole area is interpreted as the working area with the lowest readings possibly showing the main deposition of material possibly forming a pathway.

Other observations:

- The highest readings of up to 500 ppm are in the north-east and south-east corners and can be interpreted as the response from the natural geology.

Associations:

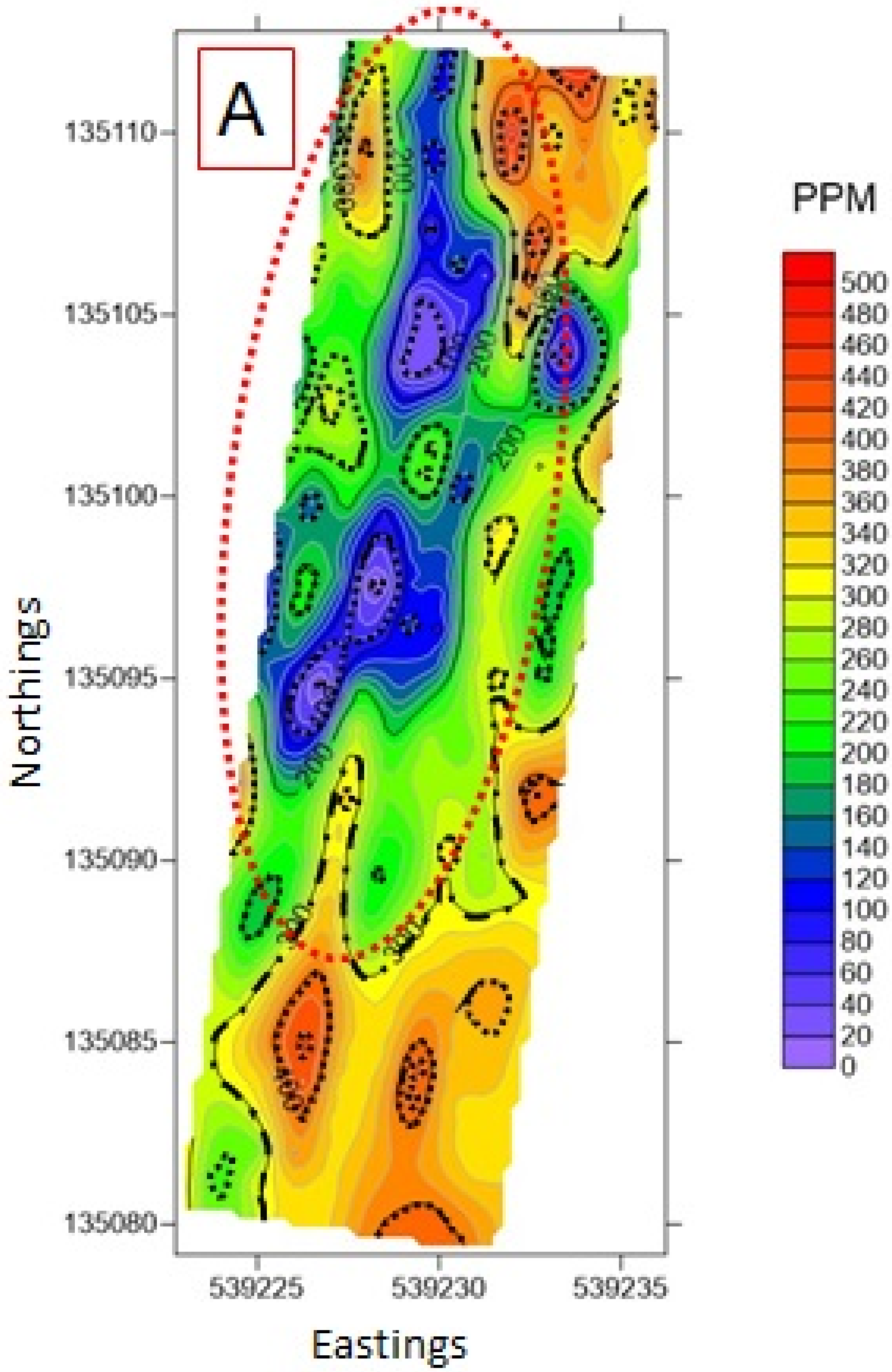

FIGURE C.24: Quadrature 3kHz Normalised and Annotated

D Case Study 2 - Standen - Excavation and Deposit Sampling

D.1 Excavation Strategy

1-The topsoil was removed with care being taken to not damage roots above 25mm thick or damage any plant bulbs that existed in abundance in the topsoil.

2-Once it was believed the archaeological deposits were being reached the base surface of the trench was levelled

3-Nails and string were then placed around the bottom edge of the trench to deliminate the top of the spit allowing for a measure reference for excavation.

4-This was then photographed, and all paperwork and sample bags prepared for the spit.

-Each sample bag noted site code, trench number, spit number and type of sample-

7-The spit was then excavated using hand trowels to a depth of 0.1m with reference to the deliminating string.

-If samples large and crossing spits size can be increased to 0.2m-

8-All material excavated was weighed and recorded as initial weight.

- Any artefacts not directly related to iron production such as pottery was sampled separately to stop damage-

9-The material was then sieved through a 25mm sieve

10-All material larger then 25mm was weighed, recorded and collected in its entirety as large samples.

11- All material to pass through the 25mm sieve was then passed through a 6mm sieve.

12- All material larger than 6mm was weighed, recorded and a 25% by weight sample taken as small samples.

13-All material to pass through the 6mm sieve was weighed, recorded and a 10% sample by weight taken as matrix.

14-All material not collected placed in a discard pile on a large tarp.

15-Once spit excavated to a depth of 0.1m according to the deliminating string and all paperwork and sampling complete a new delimainating string was inserted.

16-Steps 5 to 15 were then repeated until the natural geology was reached.

14-Once trench fully excavated the trench sections were drawn along with trench plan if any features existed.

15-Once the excavation and all paperwork were completed the trench was backfilled and topsoil reinstated

D.2 Trench Outlines

TABLE D.1: ST17-1 trench overview

Trench	ST17-1
Length/Width	2mx1m
Depth	Max 0.92m Min 0.63m
No. Spits	9
Context	101 – brown clay loam with technological waste 102 – dark brown clay loam with technological waste and fine charcoal 103 – yellow brown clay loam
Description	T1 was opened across the assumed medieval bank allowing for the investigation of this feature along with the Roman iron production waste. The leaflitter and moss was cleared from the top of the trench until archaeological debris was reached which was just below the surface. T1 contained three contexts. The first of these (101) covered the entire area of the trench down to a depth of around 46cm. The second context (102) fills the rest of the trench apart from a small area at the base on the North-West corner which contains context 103. Context 102 is similar to 101 but with increased charcoal giving it a darker colour. T1 consisted of 9 spits. Spit 1 was an odd shape due to the fact it was the lump of the bank used to level the trench ready for quantification. Spit 2-8 were kept to 10cm. Spit 9 was an irregular shape due to the natural clay being discovered. In trench 1 the only finds were that of iron production waste including slag and furnace material. Nothing was found in this trench to give any information as to the date of the creation or use of the bank feature.

TABLE D.2: ST17-2 trench overview

Trench	ST17-2
Length/Width	1mx1m
Depth	Max 0.52m Min 0.22m
No. Spits	3
Context	201 – brown clay loam with technological waste 202 – light yellow brown clay loam with technological waste
Description	T2 was excavated on the slope of the ghyll side bellow the bank feature. The top soil was removed to reach the archaeological contexts and level the surface ready for quantification. This top-level removal was to a depth of around 20cm on the uphill (eastern) side of the trench with only clearance of leaf litter and moss from the downhill (western) side of the trench. This topsoil was a brown clay loam with inclusions of iron production waste. T2 contained two contexts. The main context (201) was the same as the topsoil reaching the full depth of the trench across the North-East, East, South and South-West of the trench along with the top of the North-West. At a depth of around 6cm in the North-West quarter of the trench a second context (202) appears. T2 contained 3 spits of 10cm depth. The third and final spit was an irregular shape due to the natural clay being reached. In trench 2 a large amount of iron production waste was found including slag, furnace lining and the unidentified black glass material. There was also a single piece of pottery found at the bottom of this trench sitting on the natural clay with the iron production waste on top.

TABLE D.3: ST17-3 trench overview

Trench	ST17-3
Length/Width	1mx0.5m
Depth	Max 0.53m Min 0.22m
No.Spits	2
Context	301 - Light yellow brown clay soil with technological debris
Description	T3 was excavated on relatively flat ground just within the woodland from the field above the bank feature. The top soil was removed to try and find the surface of the archaeological layer. At around 20cm below the ground surface it was decided to attain a level to begin quantifying in spits. A defined archaeological layer hadn't been discovered by this point, but the topsoil context was looking like plough soil with an even mixture of material. Therefore, the decision was then to begin quantification in case the plough depth was down the natural clay. The trench was formed of a single context containing inclusions of iron production waste and formed of a light-yellow brown clay soil. With finds dispersed throughout the whole depth of the trench from a variety of time periods it can be said with confidence that the plough depth and farming movement has affected the entire trench. Towards the base of the trench there was more influence in the matrix from the natural clay, but this is not believed to be a sep arate context but rather due to natural processes of taphonomy. T3 contained two spits. Due to lack of time the spit size was increased to 20cm in this trench. The second spit did not reach the full depth of 20cm due to the natural clay being reached. In trench 3 a large amount of iron production waste was found including slag, furnace lining and the unidentified black glass. Also in the trench were a number of other finds. This includes two pieces of pottery assumed to date from the Roman period. There was a number of small sherd of Victorian white glazed pottery and the stem of a tobacco pipe. Cut into the natural at the base of T3 is what is believed to be the remains of a furnace. A high volume of vitrified furnace lining was removed before the feature was identified, but when it was excavation was stopped. This is so the furnace can be properly excavated and recorded in entirety at a future data.

D.2.1 section drawing

Trench 1

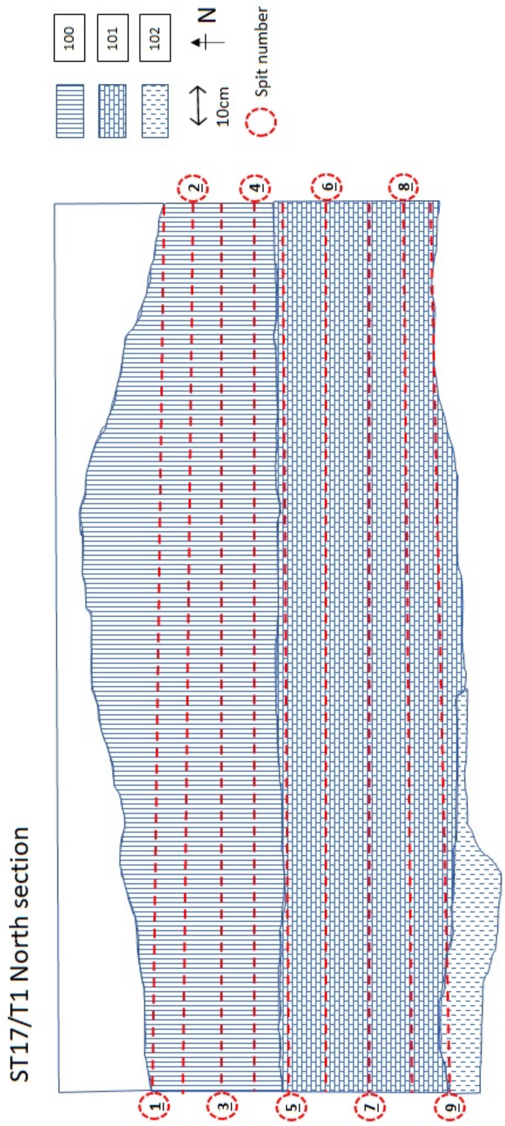

FIGURE D.1: Standen Trench 1 north section drawing

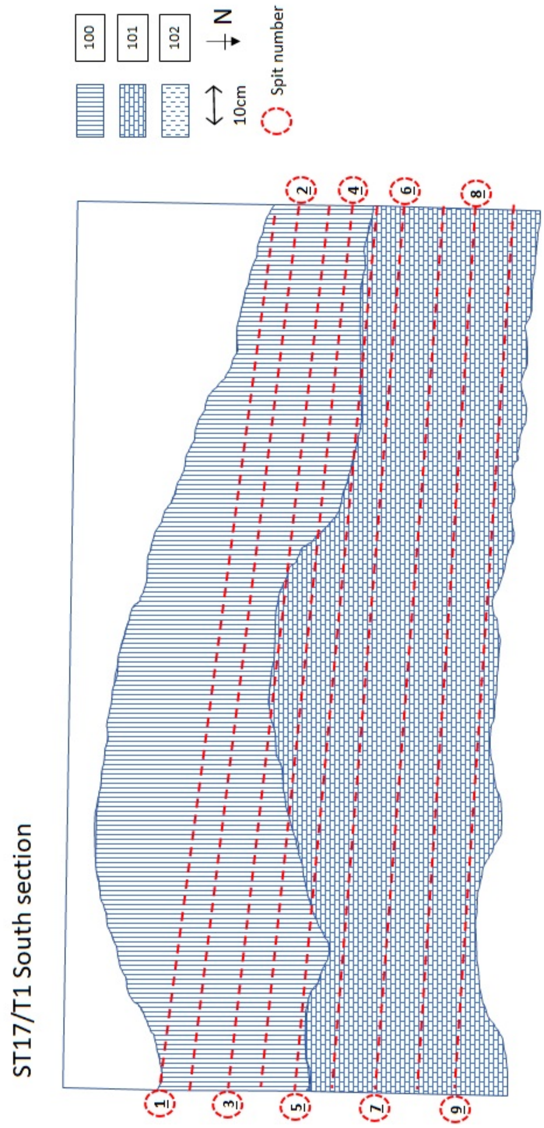

FIGURE D.2: Standen trench 1 south section drawing

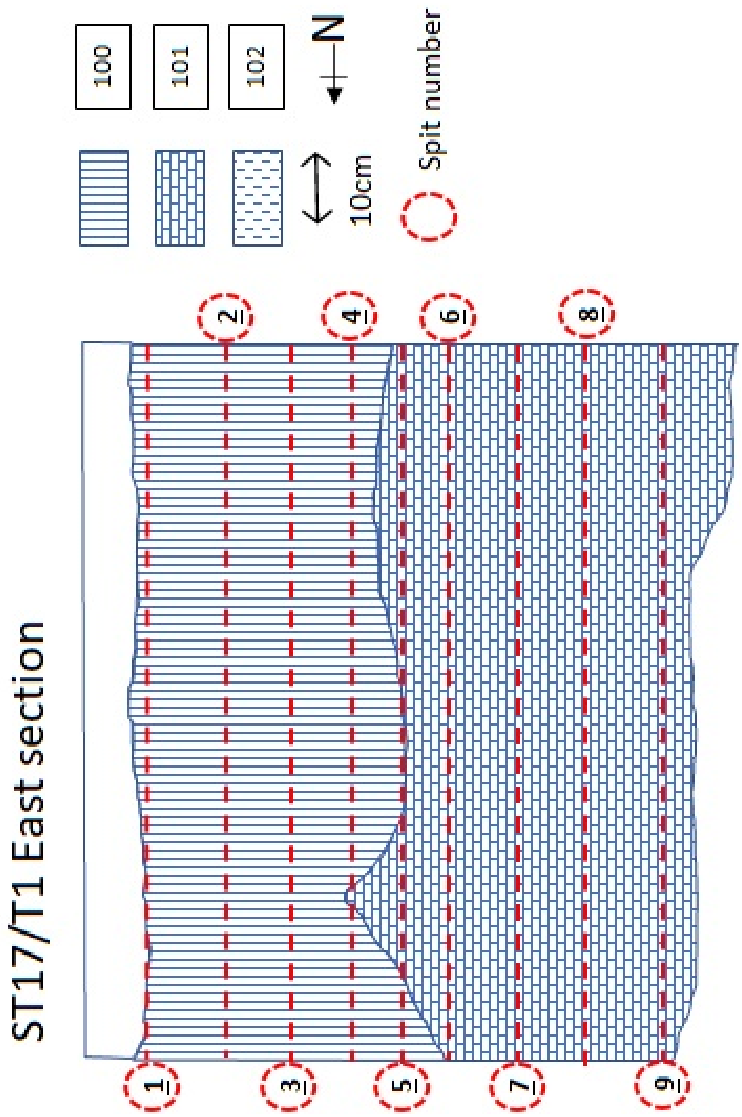

FIGURE D.3: Standen trench 1 east section drawing

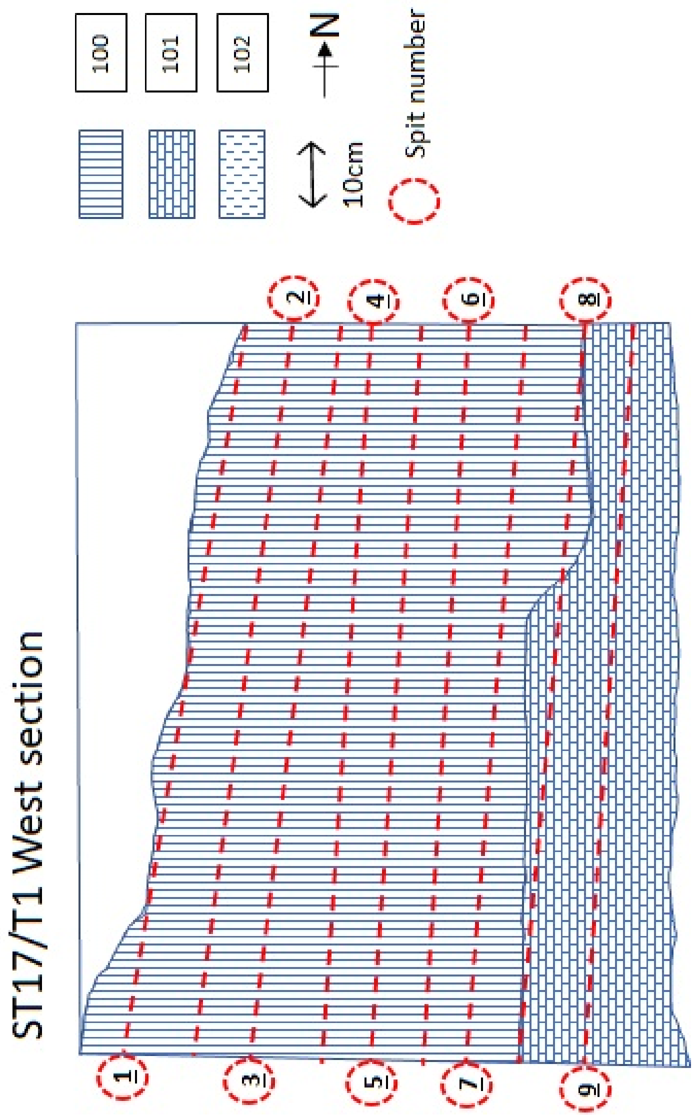

FIGURE D.4: Standen trench 1 west section drawing

Trench 2

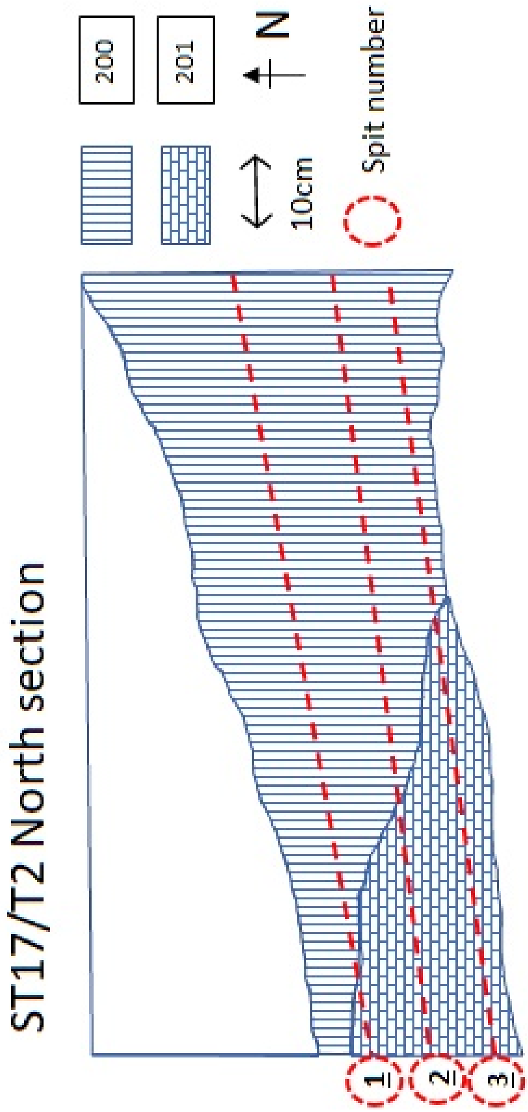

FIGURE D.5: Standen Trench 2 north section drawing

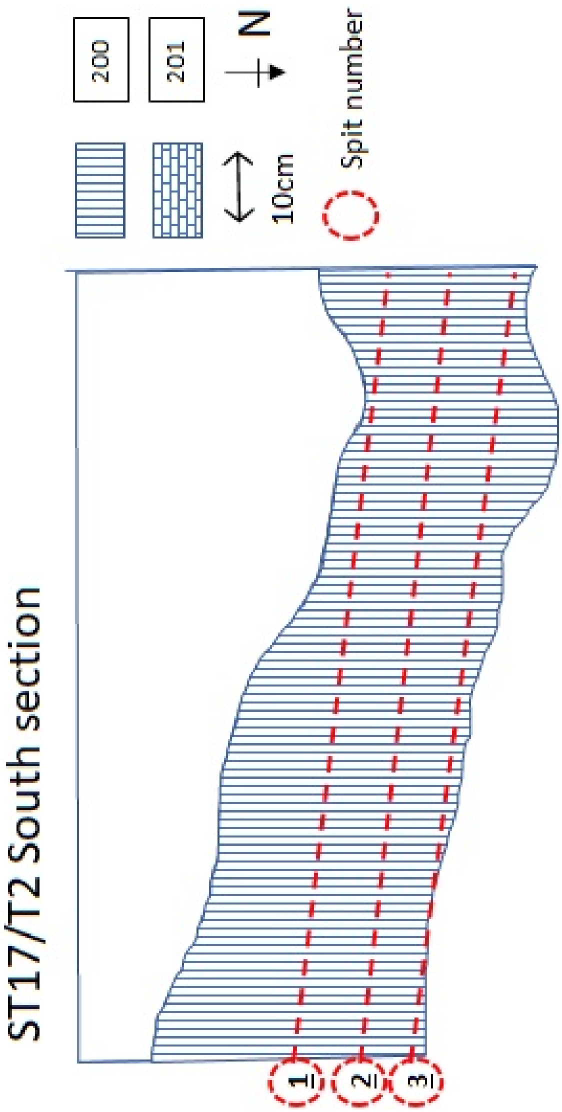

FIGURE D.6: Standen trench 2 south section drawing

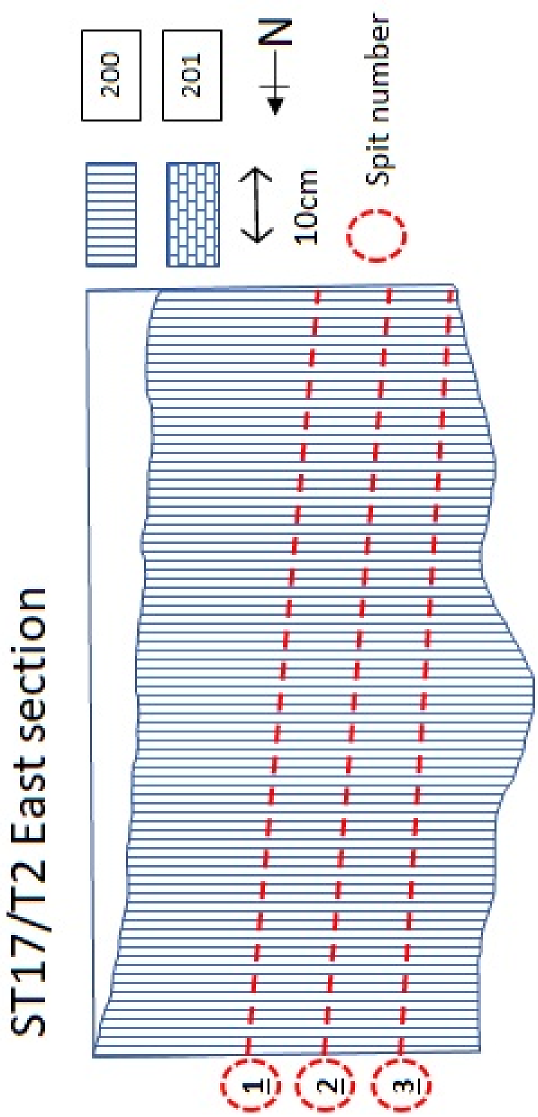

FIGURE D.7: Standen trench 2 east section drawing

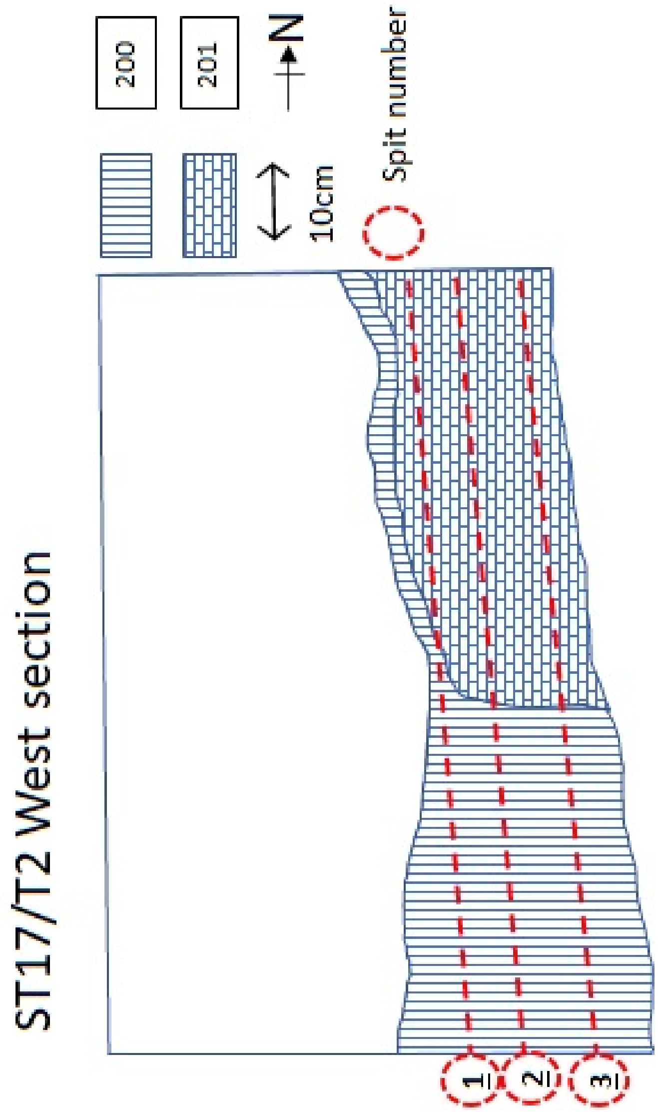

FIGURE D.8: Standen trench 2 west section drawing

Trench 3

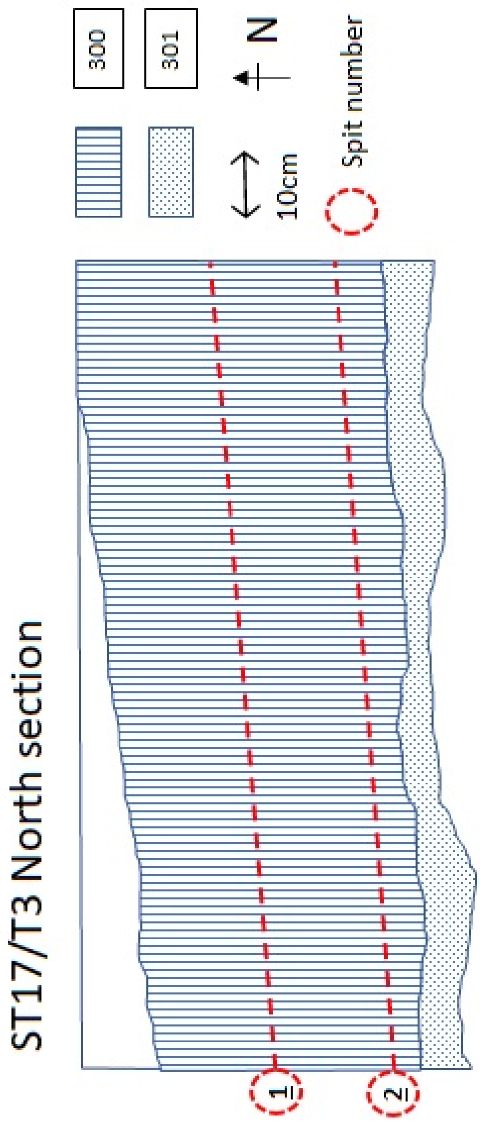

FIGURE D.9: Standen Trench 3 north section drawing

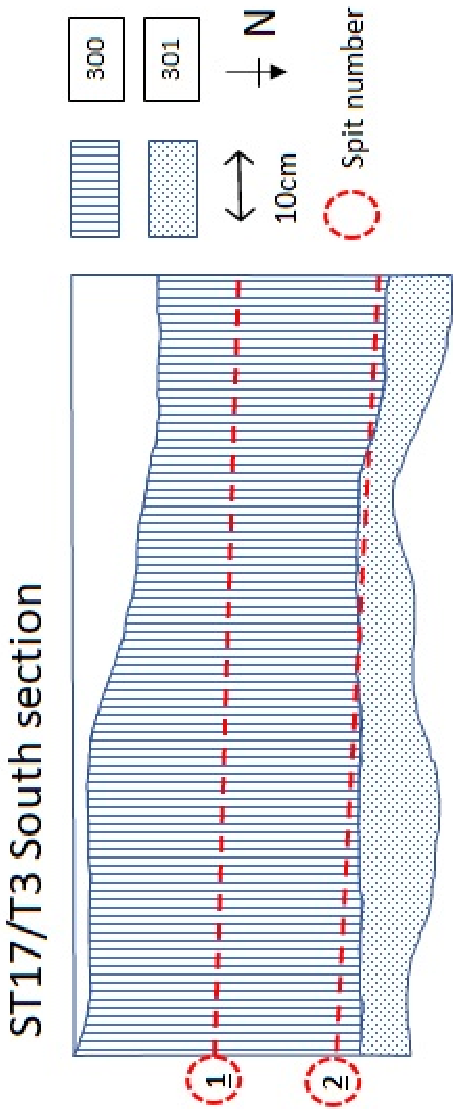

FIGURE D.10: Standen trench 3 south section drawing

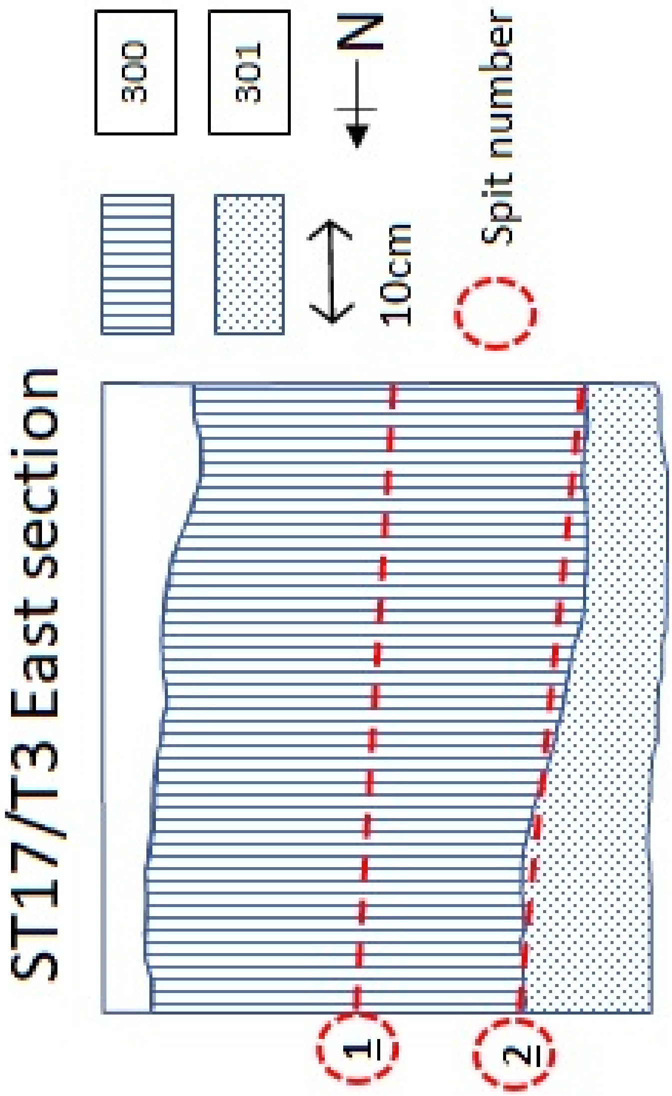

FIGURE D.11: Standen trench 3 east section drawing

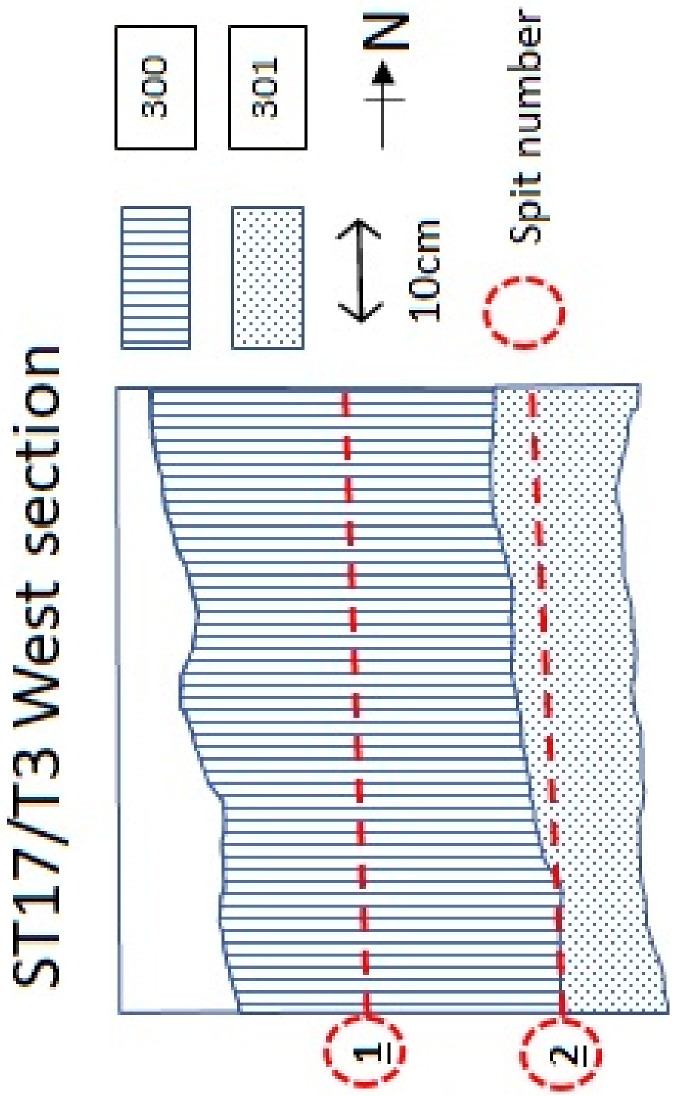

FIGURE D.12: Standen trench 3 west section drawing

D.3 Quantification

TABLE D.4: Abbreviations used in quantification tables with definitions

name	abbreviation	definition
mixed large	MLa	combination of large + MMa >25mm<6mm
mixed small	MSm	combination of small + MMa <25mm
mixed matrix	MMa	combination of matrix + FR <6mm
large	large	clean material >25mm
small	small	clean material <25mm>6mm
matrix	matrix	clean material <6mm>50μ
fine residue	FR	material <50μ
furnace material	FM	furnace material
geological	geo	geological material
not available	NA	data unavailable, reason below graph

D.3.1 Excavation weights

TABLE D.5: Standen trench excavation weights (kg)

trench	spit	EMa	MMa	Inc	Mla	MSm
1	1	306.20	143.10	163.10	80.40	82.70
1	2	158.90	88.30	82.30	32.50	49.80
1	3	297.70	180.90	116.80	82.10	34.70
1	4	287.15	110.60	118.50	61.20	57.30
1	5	268.70	101.45	16.73	80.90	86.35
1	6	233.25	85.70	165.95	74.55	91.40
1	7	206.90	64.70	142.20	72.50	69.70
1	8	173.55	71.60	129.90	62.60	67.30
1	9	73.15	36.90	36.25	21.45	14.80
1 total	all	2005.50	883.25	1122.25	5668.20	554.05
2	1	172.25	74.55	122.95	81.45	41.50
2	2	178.35	62.55	131.30	84.45	46.85
2	3	165.10	74.50	112.85	63.50	49.35
2 total	all	515.70	211.60	367.10	229.40	137.70
3	1	204.90	102.40	131.48	43.80	87.68
3	2	89.30	45.00	59.00	27.20	31.80
3 total	all	294.20	147.40	190.48	71.00	119.48
site total	all	2815.40	1242.25	1679.83	868.60	811.23

Table of abbreviations at beginning of section

D.3.2 Large Samples

TABLE D.6: Standen trench 1 - Quantification of mix large (kg)

Spit	MLa	large	slag	FM	geo	MMa	total
1	80.40	54.33	46.18	7.83	0.33	26.07	80.40
3	82.10	59.45	53.25	5.44	0.77	22.65	82.10
5	80.90	61.89	54.13	7.56	0.20	19.01	80.90
7	72.50	47.45	41.40	5.55	0.50	25.05	72.50
9	21.45	16.88	13.86	3.02	0	4.57	21.45
total	337.35	240.00	208.82	29.39	1.80	97.35	337.35

D.3.3 Small Samples

Analysed samples

TABLE D.7: Standen Trench 1 - Quantification of 1kg sample of mix small by spit level (kg)

Spit	MSm	small	slag	FM	Geo	MMa	total
1	1.000	0.513	0.465	0.037	0.011	0.487	1.000
3	1.000	0.550	0.497	0.036	0.017	0.450	1.000
5	1.000	0.690	0.586	0.084	0.021	0.310	1.000
7	1.000	0.560	0.469	0.070	0.020	0.440	1.000
9	1.000	0.313	0.208	0.089	0.017	0.687	1.000
total	5.000	2.625	2.224	0.316	0.086	2.375	5.000

Small Extrapolated Samples

TABLE D.8: Standen trench 1 - Quantification of extrapolated mix small by spit level (kg)

Spit	MSm	small	slag	FM	geo	MMa	total
1	82.70	42.43	38.42	3.08	0.93	40.28	82.70
3	34.70	19.07	17.24	1.25	0.59	15.63	34.70
5	86.35	59.60	50.56	7.25	1.79	26.75	86.35
7	69.70	39.00	32.72	4.88	1.41	30.70	69.70
9	14.80	4.63	3.07	1.32	0.25	10.17	14.80
total	288.25	164.73	142.00	17.77	4.95	123.52	288.25

D.3.4 Matrix samples

Analysed Samples

TABLE D.9: Standen trench 1 - Quantification of 1kg sample of mix matrix by spit level (kg)

Spit	MMa	matrix	slag	FM	geo	FR	total
1	1.000	0.075	0.046	0.010	0.019	0.925	1.000
3	1.000	0.100	0.058	0.008	0.030	0.900	0.996
5	1.000	0.100	0.064	0.017	0.019	0.900	1.000
7	1.000	0.100	0.062	0.009	0.029	0.900	1.000
9	1.000	0.100	0.062	0.018	0.020	0.900	1.000
total	5.000	0.475	0.292	0.062	0.117	4.525	4.996

Extrapolated Samples

TABLE D.10: Standen trench 1 - Quantification of extrapolated mix matrix by spit level (kg)

Spit	MMa	matrix	slag	FM	geo	FR	total
1	209.45	15.71	9.63	2.09	3.98	193.74	209.45
3	219.18	21.91	12.71	1.75	6.58	198.14	219.18
5	147.21	14.72	9.42	2.50	2.80	132.49	147.22
7	120.45	12.05	7.47	1.08	3.49	108.40	120.45
9	51.64	5.16	3.20	0.93	1.03	46.47	51.64
total	747.98	69.56	42.44	8.36	17.88	679.24	747.98

D.3.5 Material weights

Total Slag

TABLE D.11: Standen spit 1 - Quantification of slag by spit level. (kg)

Spit	spit weight	large	small	matrix	Total
1	306.20	46.18	38.42	9.63	94.24
3	297.70	53.25	17.24	12.71	83.19
5	268.70	54.13	50.56	9.42	114.11
7	206.90	41.40	32.72	7.47	81.59
9	73.15	13.86	3.07	3.20	20.13
Total	1152.65	208.82	142.00	42.44	393.26

Total Furnace Material

TABLE D.12: Standen trench 1 - Quantification of furnace material by spit level (kg)

Spit	spit weight	large	small	matrix	Total
1	306.20	7.83	3.08	2.09	13.00
3	297.70	5.44	1.25	1.75	8.44
5	268.70	7.56	7.25	2.50	17.32
7	206.90	5.55	4.88	1.08	11.51
9	73.15	3.02	1.32	0.93	5.27
Total	1152.65	29.39	17.77	8.36	55.53

Total Geological

TABLE D.13: Standen trench 1 - Quantification of geological material by spit level (kg)

Spit	spit weight	large	small	matrix	Total
1	306.20	0.33	0.93	3.98	5.23
3	297.70	0.77	0.59	6.58	7.93
5	268.70	0.20	1.79	2.80	4.78
7	206.90	0.50	1.41	3.49	5.40
9	73.15	0	0.25	1.03	1.28
Total	1152.65	1.80	4.95	17.88	24.63

Total Material

TABLE D.14: Standen trench 1 - Quantification of total analysed material by spit level (kg)

Spit	spit weight	slag	FM	geo	FR	Total
1	306.20	94.24	13.00	5.23	193.74	306.20
3	297.70	83.19	8.44	7.93	198.14	297.70
5	268.70	114.11	17.32	4.78	132.49	268.70
7	206.90	81.59	11.51	5.40	108.40	206.90
9	73.15	20.13	5.27	1.28	46.47	73.15
Total	1152.65	393.26	55.53	24.63	679.24	1152.65

D.4 Typology

D.4.1 Dominant types

Burnt Clay: Clay that has been affected by heat giving it This type is defined by clay that has been affected by heat giving it a variety of colours including yellow, orange, red, grey, green and blue. Textures can vary from soft and friable to very hard.

Corrogated:This type is defined by an upper surface having a corrugated texture. This is defined by a number of tightly packed ridges and can be seen in detail in PICTURE

Dense Surface: Formed of a dense slag with low porosity and fractured on 5 or 6 edges with no diagnostic features.

Fluid Movement Tendril: This type is defined by slag with a upper surface containing tendrils of slag that have flowed in a fluid nature.

Furnace Slag: high number of tendrils and signs of fluid movement with no obvious orientation and an open texture

Glassy: This type is defined by a larger portion of the slag being a glass like material, usually black in colour. It can contain a number of different textures including tendrils, messy ripples and smooth.

Light Porous: This type is defined by its high porosity % and light weight.

Magnetic: rusty colour material with slag. Highly magnetic

Messy Ripple: This type is defined by having an upper surface that shows a mixture of textures including porosity, ripples, corrugation and messy ripple This type is defined by the texture of its upper surface. This texture has a number of ridges formed in various directions.

Porous Surface: The type is defined as being a piece of slag with a large amount of porosity on a single edge only.

Sandstone: This type is defined by a geological material that is sandy to touch.

Smooth : This type is defined by having the majority of its upper surface smooth with no features.

Vitrified Mixed furnace material: This type is defined by a large portion of glassy material formed on furnace material

Images

FIGURE D.13: Standen burnt clay

FIGURE D.14: Standen corrogated

FIGURE D.15: Standen fluid movement tendril

FIGURE D.16: Standen Furnace Slag

FIGURE D.17: Standen glassy

FIGURE D.18: Standen magnetic

FIGURE D.19: Standen vitrified

FIGURE D.20: Standen dense surface

FIGURE D.21: Standen light porous

FIGURE D.22: Standen Messy ripple

FIGURE D.23: Standen porous surface

FIGURE D.24: Standen sandstone

FIGURE D.25: Standen smooth

D.4.2 Non-dominant types

Amorphous: no identifiable features and does not fit any other type

Chalk/Lime:This type is defined by a white friable geological material

Concave/Convex: This type is defined by its specific bowl like shape

Curved Slag: concave/convex (same shape as halfpipe) with FM on concave side

Cylinder Slag: This type is defined by slag that has formed in a uniform cylinder shape with a rough texture.

Dense Amorpous: dense with mix of surface textures

Dense Porous: No identifying surface features, increased density and high porosity

Dense Slag (possible furnace): dense with possible fluid movement and adhered furnace material

Dense Slag Fractured: Formed of a dense slag with low porosity and fractured on 5 or 6 edges with no diagnostic features.

Foot: This type is defined by its shape where slag has flowed down from a height forming vertical tendrils that spread horizontally.

Formed Slag Blow Hole?: This type is defined by its very specific shape that is a curve with a squared off edge.

Frothy slag: low density, high porosity with signs of possible fluid movement

Furnace cake Fragment: plano top and curved bottom like taking a slice out of a bowl

Low density: This type is defined by its light weight. This may be down to high % porosity but this was not visible from the edges of the samples.

Ore: geological material which is purple/red in colour and dusty to touch

Plano slag: plano slag with no diagnostic features but to thick to be flat

Porous Slag: slag with a large amount of porosity throughout.

Possible Cake: mixture of upper and lower surface textures with a plano top and convex bottom

Rough: This type is defined by the texture of its upper surface being rough, like course sandpaper

Rough Internal Bubbles: large fractured porosity with a rough internal texture

Undulating Surface: This type is defined by having a relatively smooth surface but with a surface that raises up and down.

D.5 Classification

A total of 4813 individual samples were classified from T1 forming 43 different types within the broad materials of slag, furnace material and geological.

spit 1

Spit One contains 1027 individual samples covering 17 types. The three most common types by weight will be set out in brief below

TABLE D.15: Classification of top 3 dominant types by weight, Spit 1

Type	FMT	Vitrified	Dense surface
Material	slag	FM	slag
Weight(g)	20480	7140	5800
Number	420	161	67
Min/max size	9x7.5 / 1.5x1.5	2x2 / 10x7	7.7x6.1 / 2.3x2.5
Shape	amorphous	amorphous	amorphous
Fracture	4-5	3-6	4-5
Porosity shape	mix	NA	spherical
Porosity size (mm)	1-16	NA	1-7
Porosity %	<20	NA	<10
Inclusions	none	none	none
Vitrification	NA	high	NA

spit 3

Spit Three contains 1308 individual samples covering 20 types. The three most common types by weight will be set out in brief below

TABLE D.16: Classification of top 3 dominant types by weight, Spit 3

Type	FMT	Dense surface	Corrogated
Material	slag	slag	slag
Weight(g)	17670	6100	5800
Number	428	91	138
Min/max size	2.8x2 / 8.6x5	3.4x2.4 / 8.6x5.5	2.2x2.2 / 7.1x5.3
Shape	amorphous	amorphous	amorphous
Fracture	3-5	5	4-5
Porosity shape	spherical	spherical	spherical
Porosity size (mm)	1-5	1-30	1-19
Porosity %	<10	<20	<10
Inclusions	none	none	none
Vitrification	NA	NA	NA

spit 5

Spit Five contains 1344 individual samples covering 22 types. The three most common types by weight will be set out in brief below

TABLE D.17: Classification of top 3 dominant types by weight, Spit 5

Type	FMT	Corrogated	Glassy
Material	slag	slag	slag
Weight(g)	14225	7400	6750
Number	296	180	154
Min/max size	2.5x3.3 / 8.9x7.8	2.7x2.5 / 11.7x7.6	2.9x2.5 / 8.5x6.4
Shape	amorphous	amorphous	amorphous
Fracture	3-5	3-5	3-5
Porosity shape	mix	spherical	spherical
Porosity size (mm)	1-4	1-6	1-11
Porosity %	<10	<15	<10
Inclusions	FM	FM	FM
Vitrification	NA	NA	NA

spit 7

Spit Seven contains 811 individual samples covering 18 types. The three most common types by weight will be set out in brief below

TABLE D.18: Classification of top 3 dominant types by weight, Spit 7

Type	FMT	Corrogated	Glassy
Material	slag	slag	slag
Weight(g)	10970	7700	4700
Number	187	130	97
Min/max size	2.7x3 / 12x8	3x2.3 / 8.5x8.3	3x2.9 / 7.5x5.5
Shape	plano	amorphous	amorphous
Fracture	3-4	3-4	2-5
Porosity shape	spherical	spherical	spherical
Porosity size (mm)	1-35	1-11	1-7
Porosity %	<5	<10	<15
Inclusions	FM	FM/ore	FM
Vitrification	NA	NA	NA

spit 9

Spit Nine contains 332 individual samples covering 14 types. The three most common types by weight will be set out in brief below

TABLE D.19: Classification of top 3 dominant types by weight, Spit 9

Type	FMT	Furnace Slag	Vitrified
Material	slag	slag	FM
Weight(g)	6300	3800	2200
Number	116	37	39
Min/max size	3.1x2.7 / 10.8x9.3	3.5x2.6 / 10.7x15.4	3.5x2.6 / 8.6x4.8
Shape	amorphous	amorphous	amorphous
Fracture	3-5	unclear	unclear
Porosity shape	spherical	spherical	NA
Porosity size (mm)	1-12	1-11	NA
Porosity %	<10	30	NA
Inclusions	FM	FM/charcoal	none
Vitrification	NA	NA	high

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