Envaluing past practice: a framework for the spatial analysis of metalworking in first millennium BC Britain

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Abstract

This thesis explores how current understandings of craft have largely restricted its analysis to the domains of material and technique. Through a critique of existing approaches to space and a reconfiguring of what constitutes craft practice, it is argued that space needs to be considered as a vital element of craft and may benefit from being considered as a technological choice. Having reconsidered the role of space, the thesis reviews and explores approaches and methods to characterising space in both archaeological and experimental contexts. The study engages with a number of analytical techniques including geophysical and geochemical methods to develop approaches to the characterisation of space in both experimental and archaeological case studies.

It is argued that the study of space and its inhabitation offers the potential to unite experimental and conventional archaeological excavation on a continuum of exploration that emphasises the active use of space and in craft contexts, encourages the use of dynamic reconstruction. A number of analytical constructs are advocated so as to allow the better use of spatial characterisation in archaeological syntheses. Ideas of technical routines and the signatures that they impart to open soil contexts are developed in the context of experimental and Iron Age case studies to demonstrate the utility of considering space as an element of craft.

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Chapter 1. Introduction

THE PRACTICE OF ENVALUATION

Practice, perhaps not conceived by, but certainly best associated with Bourdieu (1977, 1990), has become an all-encompassing term, representative of a desire to study the actions of individuals in a more socially situated manner. The concept has become so entrenched in social studies that it is rarely adequately defined, but rather is a tacitly accepted universal construct. Simply, practice is the *enactment* of agency. Further, practice has served to underpin the notion of Bourdieu's (1977) *habitus* as well as Giddens' (1979, 1984) theory of structuration as it recursively acts to both produce and reproduce the social structures within it which it presents. In this manner, through the medium of the human body, and its movements in space, we are able to witness the translation, as well as the creation, of wider societal structures into specific arenas of practice. Within archaeology the study of 'ritual' has benefitted most from this approach to past actions, but other activities have received comparatively little attention. Though practice theory, as championed by Bourdieu (1977) and Giddens (1979, 1984) in particular, has emphasised the way in which routine and mundane activities are habituated, archaeology has been slow to apply the same intellectual frameworks to contexts of everyday life.

Envaluation, as proposed by Taylor (1999), is the process by which materials, in his case metals, are imbued with meaning and social significance. In this way, metals, and materials more broadly, can be both valued and *en*valued within a culture. The latter makes reference to the roles these materials played as well as the actions they afford society and day to day practices—in essence, an acknowledgement of their materiality (Jones 2004).

> *'The notion of materiality encompasses the view that material or physical components of the environment and the social practices enacted in that environment are mutually reinforcing. The material world, and the social practices that take place in that world, bring each other into being and are therefore analytically indivisible' (Jones 2004: 330).*

Jones (2002) has largely been critical of the way in which scientific practice has been integrated into *archaeological* practice, as it pertains to how materials are characterised and considered in their social contexts. He has emphasised the actual lack of integration within these practices, due to a failure to reconcile the physical and chemical characteristics of materials with the social roles they occupy and the behaviours they afford (Bray and Pollard 2005). A few notable studies have managed to bridge this divide, and emphasise a fuller social role, not only of material culture, but of its material constituents and processes of production (Hosler 1995, 1996, 1988, Budd *et al.* 1994, Budd and Taylor 1995, Doonan and Mazarakis Ainan 2007). To some extent, the division within materials-based research still remains between the study of material culture and the production of materials, although there are an increasing number of researchers who seek to acknowledge the potency of raw materials themselves in crafting meaning in the items that are fashioned from them. Scientifically-based artefact studies will always have their place within archaeological discussions, as they provide a useful strain of evidence which contributes to our investigations of past craft production. Yet their eagerness to adhere to the strictly material, at the expense of the social role of materials, leaves these studies decontextualised (Goodway 1991, Ehrenreich 1999). Boivin (2005: 177) captures the essence of the problem; 'scientific practice generates data that answers one set of questions, while theoretical practice focuses perhaps on an entirely different set of issues'. Ehrenreich (1999: 221) quite aptly wonders '[a]fter all, did we get into this field just to find out how people smelted metal?' There has been an enduring critique of studies which solely address the technical aspects of craft production (Pfaffenberger 1988, 1992, 1999, Dobres 2010, Edmonds 1990b, 1997), not cognisant of or perhaps disregarding the situatedness of these actions (Bourdieu 1977: 83). If we can acknowledge that materials can be *en*valued and situated within their social milieu, then it seems apparent we are not limited to an understanding of physical, chemical, or mechanical properties of materials although it remains unclear how such investigations might proceed from this perspective, it seems reasonable to initiate investigations into the technical routines, and *practices*, through which materials and contexts of production are transformed.

Material culture is one of the main tenets of archaeology, forming the foundation of chronologies and cultures, establishing networks of trade, and often signifying social differentiation. Yet, the practices that serve to produce material culture are socially situated and not simple technical routines (Pfaffenberger 1992, 1999). Whilst some might insist on there being a reducible technical aspect to practices (Heeb and Ottaway 2014), they are almost always performative (Budd and Taylor 1995, Dobres and Hoffman 1999, Gell 1992). Specific practices take on their own meaning and significance as they relate to other contemporaneous social practices. Craft may be understood as a form of technology, but moreover it represents a class of routine practices that involves materials, knowledge, and tradition. Craft studies then, can serve to gather together a wide array of disciplines ranging from the physical and social sciences to the arts. It is anticipated that through widening our definition and understanding of what craft actually is, we might begin to extend the focus of our study far beyond artefacts to include not just recognisable by-products but the range of materials that occur at varied scales, including atomic chemical traces and even sub-atomic magnetic signatures. Critically, it is through the providence of such residues being spatially located and in some way related to routines of production that provides a means of broadening our conception of craft.

SPATIAL AND TEMPORAL SETTING

The period of the first millennium BC witnesses the transition from the Bronze to the Iron Age in Britain; a transition that is not defined by metal, but by broad changes in diverse social practices. Research into the Iron Age of Britain has welcomed the tenets of practice theory for the study of structured deposition (Hill 1995, Bradley 1998) as well as the occupation of ritual landscapes and domestic structures (Barrett 1994b, Barrett 1999, Giles and Parker Pearson 1999). However, to date the approach has not extended to the routine study of craft in a meaningful way. Craft, metalworking, pottery, flint knapping, *etc.*—represent a coalescence of social practices that serve to produce and reproduce much of the recoverable material residues of the past. Practices such as, the deposition of bronzes and the ways in which the spaces of houses were occupied are perhaps often readily visible in the archaeological record, and certainly more widely reported. However, the frequently subtle, yet detectable, traces of craft afford the opportunity to examine a practice that is both quotidian and often situated in between spaces among recognisable features. This aspect of craft offers the opportunity to augment our understandings of substantial architecture and more eccentric practices, with insights into the routine and the mundane. The routine and mundane, while superficially unappealing, offer the security of the commonplace, as such practices are likely, although not always, representative of everyday lifeways.

The subject of craft in the Iron Age, and in particular, the Early Iron Age, is attractive as this time witnesses the earliest coexistence in Britain of two quite different metallurgical traditions: bronze and iron. In discussing emergent iron technology, broad narratives of the period have often focused on bronze's use for prestige goods such as swords, and iron's use for the fashioning of lowly agricultural implements—only giving these materials meaning through their end use (Cunliffe 2005, Collis 1997). While bronze and iron share undeniable metallic properties, they derive from very different production histories. This difference is not simply limited to geological origin but also technical process. It is through these differing production practices that these metals become endowed with different meanings even before they acquire artefactual form.

To-date there are few studies which have considered how these metals might have been worked and valued by their practitioners and in turn how this has constructed their value. Through the development of methodologies for the recovery of metalworking practice, we can perhaps begin to better understand the differing manners in which these two metals were envalued by the Iron Age communities, as evinced through their productive acts. There is the potential to develop a comparative understanding of how different production choices were articulated in space and corresponding temporal aspects of different metal production events. In doing so, it should become possible to think more clearly about how resources, place, and skills were brought together in the Iron Age and these two distinct metallurgical traditions complemented one another. However, before such enticing aims are considered we need to recognise that at present we lack the routine methods and theoretical frameworks to employ such approaches beyond the minimally descriptive.

RECOVERING RESIDUES

This study aims in part to establish the conditions for the investigation of an extended concept of craft, in particular metallurgy. Central to this, is the clarification of a theoretical project that allows space to be acknowledged and valued as an element of craft. Allied to this is the need to identify and analyse the residues of craft practice in a manner that generates empirical data. Metallurgical production produces visible residues, ranging from slag and discarded crucibles to metal spillages and vitrified hearth fragments. However, beyond these macroscopic remains are the microscopic traces of past activities that enter open soil contexts. The raw materials of metallurgical production—heavy metals, *i.e.*, copper, zinc, iron, tin, lead, *etc.*—can and do directly impact their environs in a discernible manner (*e.g.*, Oonk *et al.* 2009a, Jouttijärvi 2009, von Steiger *et al.* 1996). Further, the temperatures associated with bronze and iron metallurgical processes (*i.e.*, 600-1250 °C (Craddock 1995, Tylecote 1986)) are significant enough to affect the thermoremanent magnetism of soils in which they are situated. The ability of metallurgical processes to impact their immediate environment both chemically and physically makes them potentially suitable to reveal both the nature and extent of past actions within defined places.

In order to investigate these interactions between metallurgical practice and detectable residues, an experimental campaign of metalworking has been conducted. Numerous other experimental endeavours have considered metallurgical production before, though the majority have done so from the perspective of technical and material requirements, *e.g.*, ore or air inputs, slag and metal outputs, process efficiencies and process parameters, such as atmosphere composition (*e.g.*, Crew 1991, 2013, Merkel 1982). In contrast, the experiments carried out as part of this study were focused on the direct observation of practitioners' engagement with experimental features and the experimental space itself. Multiple metallurgical practices were explored at differing scales, including iron smelting, iron smithing, copper smelting, and copper casting.

RESOLVING ROUTINES

In order to best connect the *residues* of practice to practice itself, one needs to be versed in the concepts of time, space, agency, and materials. A theoretically informed analysis of the residues of practice was essential for appreciating the manner in which actions and agency can be inscribed into place. Thus an examination of the tenets that underlie the construction and analysis of space alongside actions was undertaken through considering the work of major thinkers in this field (Heidegger 1962, Giddens 1984, Barrett 1988, 2001, Ingold 2000, Merleau-Ponty 2002, Lefebvre 1991).

The empirical data generated through geochemical and geophysical analysis are represented as a static pattern derived from past practices. The combination of archaeological and experimental approaches was undertaken to explore the possibilities and challenges of moving towards the animation of this data through an understanding of it as signatures of practice.

In summary, this thesis aims to expand our conceptualisation of craft so as to bring elements other than material and (bodily) technique within the routine frame of archaeological analysis. In addressing this aim the study will work between social theory and experimental archaeology while situating its preliminary archaeological workings in the British Iron Age. In doing so this thesis will undertake reviews of metallurgical practice and the use of space in later British Prehistory (Chapters 2 and 4); develop a systematic rationale that expands our concept to craft to include space as a technological choice (Chapter 3); review of how space is currently characterised at varying scales and via differing methodologies (Chapter 5); conduct a series of experimental and archaeological studies that provide opportunities for the exploration of the methods for the characterisation of craft space (Chapters 6 and 7); and develop a critically constructed research framework that utilises newly developed analytical categories for the study of agency and redefined craft space (Chapter 8).

Chapter 2. Contextualising the Past

INTRODUCTION

This chapter seeks to set the stage for the later analysis of metal production contexts. The British Iron Age represents a well-studied period which witnesses both fundamental changes in the character of metalworking practices alongside changes in the manner in which space was defined and used (Ehrenreich 1985, Sharples 2010). These two facets of the period make it the ideal spatial and temporal setting for an investigation of past metal production though the residues of these processes.

The Iron Age, so commonly defined by the eponymous process of iron metallurgy, is more appropriately characterised by widespread changes, in land division and enclosure, funerary practices, and material culture (Sharples 2010, Cunliffe 2005, Haselgrove and Pope 2007). Treatments of the period have often focused on the *emergence* of iron metallurgy and the conditions that give rise to the Iron Age (Pleiner 1980). This position remains blind to the diversity of metallurgical practices during the first millennium BC as well as the broader changes taking place at this time. It is through these changes that one can establish the broader conditions within which such communities became 'iron-using', rather than how iron metallurgy *emerged*. Considering metallurgy, both copper and iron, alongside the range of contemporary social practices, serves to remind us that metallurgy, and craft in general, cannot usefully be reduced to abstract technical processes that fail to include human choice and shared social values (Budd *et al.* 1994, Budd and Taylor 1995, Dobres 2000, Ingold 1997, Pfaffenberger 1992).

Metallurgy is a fully social practice entangled in other diverse practices. Acknowledging this is important, as it highlights the point that neither iron nor copper metallurgy can be invoked singularly to explain either local or broader patterns of change. The hermeneutic challenge then is to reveal how this specific social practice is meaningfully situated amongst others whilst accommodating it as a dynamic practice which varies through time and space. From the mining of ore to forging of iron or casting of copper, these practices are embedded equally in the landscape and existing traditions; consequently, such embeddedness demands a sophisticated analysis, which seeks to reveal the multidimensional relations that extend beyond the material processes that are, in part, metallurgical. From this perspective it begins to become clear that the study of metallurgy is not one that can be reduced to the study of materials or technical processes but one that must establish the diverse conditions under which such practices become viable.

FORGING THE IRON AGE

Highlighting changes in diverse social practices forces us to critically consider how the chronological term 'Iron Age' has become synonymous with this period of social change. In Britain, its definition has been problematic since its creation in the 1800s (Thomsen *et al.* 1836); not until the 1960s were hypothetical continental invaders rejected as the impetus for changes witnessed in material culture and building practices and the seemingly *radical* notion of a native British Iron Age allowed to fully develop (Hawkes 1931, 1959, Clark 1966, Clarke 1972). Chronology and periodisation remain a problem. Despite it being ten years since the Iron Age Research Seminar published its research framework, 'Understanding the British Iron Age: An Agenda for Action', there remains little clarity to be found across Britain as a whole (Haselgrove *et al.* 2001). To a large extent this is to be expected, as the changes witnessed in later prehistory were both chronologically and regionally bounded. With the evident variation making wider ranging comparisons challenging, the period resists easy synthesis.

Continental Influences

Thomsen first proposed an 'Iron Age' as part of his Three Age System based upon the careful observation of stone, bronze, and iron artefacts housed in the Danish National Museum (Thomsen *et al.* 1836). The general progressive sequence of material/technology noted by Thomsen was given chronological firmness, according to Cunliffe (2005: 3), by the excavations at the site of Hallstatt in Austria and the excavated votive deposit at La Tène on Lac Neuchâtel in Switzerland in the mid-nineteenth century (Sacken 1868, Déchelette 1908). At Hallstatt, Ramsauer found a salt mining community and their cemetery located alongside an alpine lake within an alluvial fan (Collis 1997: 75). The metalwork from these graves, along with the substantial deposit of weaponry found at La Tène served as the basis for a chronology defined by Reinecke in the early twentieth century (Collis 1997). This chronology was then adopted within Britain using typologies based on Hallstatt swords and La Tène brooches. This typological approach served to support invasion theories, *en vogue* during the first half of the twentieth century and gave little weight to native developments in settlements, material culture, and mortuary practices.

Locating the Iron Age

The defining characteristics of the Iron Age do not coincide neatly with the inception of iron use in Britain, as the Three Age System might imply. Neither does the period track well with the observed changes in burial practice and land use that occurred during the latter half of the second millennium BC (Cunliffe 2005, Yates 1999). The emblematic hillforts cannot be attributed *en masse* to the period, as several have been shown to have their origins in the Late Bronze Age (Needham 2007, Sharples 2010). Despite clear evidence that hillforts are built both before and after 800 BC—the notional beginning of the Iron Age (Sharples 2010), they continue to be held as the iconic feature of the period, in part due to the efforts of Cunliffe to classify this group of monuments chronologically, so that the 'true' hillforts could still be the product of Iron Age peoples (Cunliffe 2005).

The dating of the Late Bronze Age and Early Iron Age transition has suffered greatly from the imposition of the template of Thomsen's Three Age System. The legacy of this system breeds chronologies, which are clearly focused on dating the beginnings and ends of eras by the arrival of new technologies. At the crudest level, such schemes are sometimes guilty of seeking an actual date to attach to the 'switch' from bronze to iron use. These chronologies choose to subsume changes in peoples' actions and behaviours under the mantle of technological change, privileging material culture over socio-cultural structures themselves. A complicating issue for Iron Age chronologies is the 'wiggle' or plateau in the radiocarbon calibration curve starting around 800 BC. Chronological resolution for the period of 800 to 400 BC, ostensibly the Earlier Iron Age, will always be problematic until the improvement and widespread use of other dating techniques (*e.g.*, archaeomagnetic dating); though the application of Bayesian statistics does hold some promise (Cunliffe 2005: 652, Batt 1997, Pearson and Stuiver 1986, Stuiver and Pearson 1986, Clark *et al.* 1988, Buck *et al.* 1996). Dating for the period in question has instead been forced to rely on chronologies based upon ceramic and metalwork typologies, perpetuating the over emphasis on material culture in dating schema.

The problems of synthesis are further complicated by inconsistent chronological schemes across Britain. Historic England (formerly English Heritage) records, as well as the vast majority of local Sites and Monuments Records or Historical Environment Records, give dates for the Bronze Age ending circa 800 BC and the Iron Age beginning thereafter. However regional frameworks reveal differing chronologies with the start of the Iron Age ranging from 800 to 600 BC, often times with a considerable 'transition' period following the end of the Bronze Age (Webster 2008, Lambrick 2010, Cunliffe 1971, 1984a, 1984b, Cunliffe and Poole 1991a, 1991b, Kidd 2009).

While consistency may be praised in some respects, this firm dating scheme belies much regional variation, even within the areas of the record offices themselves. The southwest of Britain, encompassing the counties of Cornwall, Devon, Dorset, Somerset, Wiltshire, and Gloucestershire, is the only region to broadly conform to the Historic England chronology (Webster 2008). Only one other county in the south appears to have a chronology suggestive of the Historic England dating scheme. But it must be noted that this county, Hampshire, is home to the site of Danebury and its well stratified ceramics that have been the basis of not only Hampshire's but much of Iron Age Britain's chronological schema (Lambrick 2010, Cunliffe 1971, 1984a, 1984b, Cunliffe and Poole 1991a, 1991b). For the vast majority of the remaining counties in the south and east, 800 BC may mark the end of the Bronze Age proper, but at the same time the beginning of at least a century long transitional phase prior to any fixed Iron Age. Buckinghamshire trumps its neighbours in having a particularly ambiguous chronology for the first millennium BC (Kidd 2009). For this county, the Bronze Age ends in 800 BC but only to make way for three and a half centuries of Late Bronze Age to Early Iron Age transition leading into the Early Iron Age or the continentally borrowed La Tène period. Just as 800 BC is a relatively safe ending point for the Bronze Age in the south and east, 600 BC can be seen as another conservative estimate of the beginning of the Iron Age, leaving many to wonder just what was happening or in this period of chronological limbo in the middle of the first millennium BC.

Across the south are to be found certain pottery styles along with regional variants which Cunliffe has utilised in dividing up the region into smaller zones (Cunliffe 2005). However these traditions are geographically limited and do not continue northward or across the Welsh Marches. Furthermore, these regions are largely known for being practically aceramic during the first millennium BC, highlighting once again the fragmented nature of Iron Age material culture upon which most chronologies are hinged. In the Midlands and Wales one begins to encounter another chronological scheme for the first millennium BC. Broadly the Bronze Age extends to the end of the eighth century BC (*ca.* 700 BC), either initiating another transition period or in the case of Herefordshire and Shropshire, a defined Early Iron Age (Gale 2010, Dalwood 2002, Hancocks 2002, White 2002, Wigley 2002a, 2002b). The blanket period of the transition for these regions is even broader in its scope, including not surprisingly the Late Bronze Age to Early Iron Age transition but also the period of the Earlier Iron Age itself.

While there may be some general agreement about when and what the Bronze Age is; there is no such consensus for the Iron Age, despite syntheses that purport to discuss the period for Britain as a whole. Though it might seem a bit of a semantic argument, the differing 'nomenclature' for the Iron Age across Britain *is* indicative of underlying hetero- rather than homogeneity. The original tripartite model of Early, Middle, and Late is giving way to schemes that envision an Earlier and Later Iron Age (Haselgrove and Pope 2007, Haselgrove and Moore 2007). But despite similar names between chronologies there is limited agreement on the bounds of the Earlier and Later Iron Ages. For some regions all hope of subdividing the Iron Age has been lost, replaced with an 'undifferentiated' Iron Age, which seemingly subsumes any inherent variation within. The indeterminate chronological resolution leaves one wondering what this period stands for and where exactly the Iron Age was situated within prehistory.

A split at 450 BC has been generally adopted in British chronologies at the regional level to reflect the end of the Early Iron Age in tripartite schemes, however Historic England is more conservative in placing the Early / Middle Iron Age break at 300 BC (Historic England 2015). The notion of a Late Bronze Age / Early Iron Age transition period spanning 800 - 600 BC (Hill 1995) is well supported in regional literature. Though as one moves further north the period shrinks to 700 - 600 BC. Still one needs to ask what dictates where and when the split can be made between Bronze Age and Iron Age as material culture is often scarce and settlements are rarely continuous.

The three Iron Age sites discussed in detail as case studies (see Chapter 7, Glastonbury Lake Village, Meare Lake Village, and Maiden Castle) all date broadly to the Later Iron Age, which for the Southwest is defined as beginning in 400 BC (Webster 2008), though would all considered to be Middle / Late Iron Age sites by Historic England's chronology. Meare Lake Village is the older of the two wetland sites discussed and is dated to the 3rd century BC to the 1st century AD (Bulleid and Gray 1948, Gray and Bulleid 1953, Gray 1966). Glastonbury is considered to have developed in the next century and dates from the 2nd century BC to 1st century AD (Bulleid and Gray 1911, 1917, Coles and Minnitt 1995). Maiden Castle is an exceptionally long lived site with foundations in the Neolithic, however the area of the hillfort examined as a case study for this thesis is strictly Iron Age in date (Wheeler 1943). The phase of the site revealed in the particular excavations to be discussed dates from the 5th to the 1st centuries BC (Sharples 1991), placing it predominantly within the Later Iron Age of Southwest Britain, but also the Middle Iron Age of Historic England's chronology.

The beginning of the first millennium BC has been seen as uninteresting (Collis 1996). However, it is this period that witnessed the widespread division of the land, large-scale feasting, and a shift to permanent settlement, along with the inception of iron metallurgy. Together, this is illustrative of the initial materialisation of recognisable sustained communities in Britain; something nothing short of fascinating (Sharples 2010).

Most important for this study is the emergence of iron working technology. Iron technology needs to be acknowledged as a radical technology, whilst seeing it as a fully social phenomenon that can be understood without resorting to deterministic explanations. Concurrent changes in material culture and associated practices witnessed at the end of the Bronze Age in specific regions suggest interesting parallels with metallurgical developments. In particular, the tradition of haematite-coated pottery in Wessex, identified by Maud Cunnington's work at All Cannings Cross, notably makes use of the same resource of iron ore (Cunnington 1923). There can also be found evidence of an intensification of land division in the form of field boundaries beginning in the latter half of the second millennium, potentially indicative of attempts by people to classify the landscape into controlled rather than wild land as they began to settle in a more permanent manner (Sharples 2010). The typical practice of communal and individual barrow inhumation in the Neolithic and Early Bronze Age gave way to individual urn cremations from the Middle to Late Bronze Age (Cunliffe 2005). Lastly, despite ample evidence for change at the end of the Bronze Age, one of the most commonly witnessed explanations for the Late Bronze Age to Early Iron Age transition is simply that not much happened—a once popular supposition that when reconsidered from the perspective outlined here becomes untenable.

A LAND IN TRANSITION

Land Division and Agriculture

By the end of the second millennium BC evidence for arable agriculture expanded and for much of lowland Britain pollen evidence showed that woodland clearance was largely complete (Dark 2006, Amesbury *et al.* 2008, Hill 1995, Cunliffe 2005: 28-29, Harding 1982: 420). Throughout the Middle Bronze Age coaxial field systems were laid down in diverse landscapes to divide land for cultivation and pasture (Yates 1999, 2001, Cunliffe 2004, 2005, Fleming 1988). On Dartmoor, Fleming (1988) revealed in the 1970s that the reaves—stone-faced banks or walls—had been used to divide the land into territories based upon river valleys, which were further subdivided for pasture. In Wessex, it is challenging to chronologically link the carefully laid out field systems with contemporary settlements; making it all the more difficult to understand how these landscape features were utilised by Bronze Age peoples (Field 2001: 59). However by the end of the Bronze Age these field systems ceased to be constructed and existing ones were not maintained into the Early Iron Age (Bradley and Yates 2007: 96, Yates 1999). It is easy to see indications of the increased utilisation of grains in the form of quernstones common on sites roughly contemporary with the appearance of coaxial field systems across the landscape as proof of a preoccupation with agriculture. But one cannot take this as wholesale evidence of a complete focus on increasing agricultural productivity, as well as a resort to ecologically deterministic models (*cf.* Yates 2001).

> *'The belief that the coaxial field systems helped to maximize the agricultural production of the landscape seems to be an attempt to compare these with the enclosures of the seventeenth and eighteenth centuries AD' (Sharples 2010: 41)*

If these coaxial field systems were symptomatic of Bronze Age peoples' attempts to maximize the productive capability of arable land, in an environment that was increasingly inhospitable to agriculture, it is unclear why they were abandoned in the ensuing centuries, when the climatic downturn reached its nadir (Harding 1982).

In the Late Bronze Age and at the beginning of the Early Iron Age linear boundaries came to dominate the landscape, often ignoring the orientations of earlier coaxial fields (Cunliffe 2005: 420, Giles 2007b, Sharples 2010). Interestingly, whilst these linear ditches did not respect the earlier field systems of the Middle Bronze Age, examples from the Yorkshire Wolds 'show a consistent fascination with the barrow cemeteries of the Later Neolithic and Early Bronze Age' (Giles 2007b: 113). In the Early Iron Age there was another form of linear feature—the pit alignment—that appeared across

Britain (Wigley 2007: 119, Cunliffe 2005). These pit alignments acted as relatively permeable boundaries, and represented another way of dividing up or categorising the landscape without actually restricting the flow of people or animals. Intriguingly, these alignments too, have been shown to be respectful of earlier funerary monuments whilst ignoring prior field systems (Wigley 2007: 123). This deference for the funerary monuments of the preceding millennia is perhaps indicative of the wider sense of community burgeoning in the Early Iron Age. These monuments, representative of ancestors or at least earlier practices, were possibly revered by the people as a tangible connection to the past. Barrett states that ‘the Iron Age was actually an inhabitation of Bronze Age residues’ (1999: 258). Yet, rather than simply seeing this as a passive process, it would seem that Iron Age peoples actively chose which parts of the past to acknowledge, focusing on the more distant ‘mythical’ past rather than the comparatively recent Middle Bronze Age.

Bradley and Yates note that rather than apportioning tracts of arable land, the ‘ditches and pit alignments seem to have marked the limits of zones of productive land’ (2007: 99) suggesting a preoccupation, not with individual agricultural yield, but instead with the categorisation of the landscape as a community resource (Sharples 2010: 42). These boundaries served their function on a communal, rather than individual level, as they delimited the wild from the tamed in the landscape, as opposed to marking out one individual’s farmland from another’s (Bradley and Yates 2007: 97, Sharples 2007: 174). The importance of that which was bounded and unbounded is a theme that runs throughout the Iron Age.

Enclosed Settlements and Bounded Communities

Enclosure across all forms of settlement comes to define the first millennium BC (Thomas 1997: 211). Roundhouses are commonly situated within enclosed settlements, the duns and wheelhouses of Atlantic Scotland act as compounds themselves, and the iconic hillforts of the period are the physical manifestation of an overarching investment in boundedness (Harding 2004, 2009, Sharples 2010, Bowden and McOmish 1987). With enclosure comes a greater sense of permanence reinforced by the houses and settlements of the first millennium BC appearing to be longer lived than their predecessors (Cunliffe 2005). Roundhouses were not a phenomenon unique to the Iron Age, but instead represent a form of construction equally common to the later Bronze Age. However, the roundhouses of the Bronze Age differed greatly in size and purpose to those that became emblematic of the succeeding period. At Middle Bronze Age sites such as Itford Hill and Black Patch, multiple small roundhouses are found in nucleated groups; each house often serving as the locus for different domestic activities (Burstow and Holleyman 1957, Drewett 1982). At Itford Hill, the houses themselves were not all contemporary and instead represent a sequence of building projects across the extent of the site, rather than the rebuilding of the structures within the same location—a practice that becomes customary in the Iron Age (Barrett and Needham 1998, Cunliffe 2005: 46, Ellison 1978, *cf.* Brück 1999). The settlements of the Middle Bronze Age were not ephemeral like their predecessors (Bradley 1984, Darvill 2010); however the roundhouses that were often rebuilt were commonly relocated around the site. In contrast, the roundhouses of the Early Iron Age in southern England were grand in scale (*e.g.,* Pimperne, Longbridge Deverill Cow Down, Dunston Park, Little Woodbury) and often rebuilt in the same location multiple times with special deposits being thought to mark the occasion (Harding *et al.* 1993, Chadwick Hawkes 1994, Fitzpatrick *et al.* 1995, Bersu 1940, Thomas 1989). Additionally, the spatial separation of tasks among roundhouses witnessed in the preceding millennia was not seen in the Iron Age, instead the roundhouses of this period became the focus of a full host of domestic activities as well as the settlement as a whole (Barrett 1989a: 312, Parker Pearson 1996: 120).

These iconic large roundhouses of the Iron Age uncovered and largely recreated (*e.g.,* Butser Ancient Farm) within the South Central region of Britain are both a geographically and chronologically restricted phenomenon. Bersu's iconic Little Woodbury (Bersu 1940) and others such as Pimperne (Harding *et al.* 1993) or Long Bridge Deverill Cow Down (Chadwick Hawkes 1994) are representative of a class of roundhouses monumental in scale that greatly exceeded the dimensions of both their Late Bronze Age predecessors (*e.g.*, Black Patch and Itford Hill, Burstow and Holleyman 1957, Drewett 1982) and their Middle Iron Age successors (*e.g.*, Danebury, Cunliffe 1984a, Cunliffe and Poole 1991a). It can be argued that the size (or perhaps grandeur) of these houses allowed them to fulfil a different social role to other seemingly similar roundhouses in the first millennium BC. Perhaps like the large communal construction efforts witnessed in the hillforts and extensive land boundaries of the period, these houses were the concretisation of social practices and norms that valued the communal over the individual.

Nevertheless whilst these roundhouses may not be the norm across the whole of Britain in the Iron Age, they do represent a significant class of architecture that exhibited particular propensities in terms of spatial orientation as well as internal organisation of space (see Chapter 4 for further discussion) belying what is considered to be a greater preoccupation with space in the period. Outside of the class of these grand roundhouses other house structures are found to exhibit similar regular spatial orientations such as the MIA houses at Danebury (Cunliffe and Poole 1991a) or the houses within Moel y Gaer (Guilbert 1975). It seems then that while the scale and the geographic location of construction changed, some of the attitudes towards what constitute the right way of building and living persisted. It is this preoccupation or perhaps more appropriately awareness of a way of going about things that becomes so evident in the first millennium BC and more specifically the Iron Age. Whilst these behaviours or notions may have existed for centuries or millennia prior it is not until this late stage in prehistory that they become codified on such a grand scale.

Despite an abundance of evidence of a greater occupation with space in the Iron Age, it needs to be made clear that this was not a period of national or even regional unity. In the Late Bronze Age we can observe an extensive material culture zone represented by Deverel-Rimbury pottery across Southern Britain. However, in earlier prehistoric Britain material culture zones were even more expansive and the vast majority of pottery from the earlier Bronze Age and late Neolithic in Britain on the whole can be characterised as either collared urns or beakers (Parker Pearson 1993). Whilst the Bronze Age of Britain was relatively homogenous in its ceramic repertoire, there is no such uniformity in the subsequent period. The Iron Age is epitomised by communal—rather than regional—identity as expressed through material culture, monumental building projects, and ultimately the gift of labour (Sharples 2010). In the South Central region these building projects focused upon roundhouses and hillforts, whilst to the southwest more attention was paid to constructing small enclosures perhaps utilised for transhumance within the extensive reave system (*e.g.,* Kestor, Fox 1954). To the East communities existed largely without monumental enclosures (save for the Late Bronze Age ringworks), but there is evidence of coaxial field systems that divided the landscape during this period that are in need of further investigation in a region where open unenclosed settlements predominated (Bryant 1997, 2000). In the Thames Valley throughout the Iron Age open settlement was prevalent with groups of houses collected into hamlets that appear to have practiced some form of seasonal transhumance as they moved about the gravel terraces of the Thames (Hingley 1984, Hingley and Miles 1984), living independent of the hillforts that dominate the landscape and presumably the lives of Wessex. In the Middle Iron Age a new settlement type, one that is closed rather than open and evoked ideas of cattle kraals, emerges in the region: Banjo enclosures (Cunliffe 2005, Hingley 1984, Moore 2007). These settlements are not long lived, dying out in the Late Iron Age, but apparently served a new function within the landscape of the Thames Valley and beyond. Within the Thames Valley as well as further north and west in the Midlands and Welsh Marches is found copious evidence of another form of boundary (albeit non-monumental): pit alignments, which created permeable yet visible barriers within the landscape (Wigley 2007, Moore and Hingley 2011).

Lastly, the hillforts that have become synonymous with the Iron Age are of course not a homogeneous occurrence across Britain, whilst they predominate in the South Central region and the Welsh Marches, they are present in small numbers throughout other areas of the South, but largely absent in the North save for a handful in Yorkshire and the Northeast (Cunliffe 2005, Harding 2012). Further, within the hillfort-dominated zone proper there are areas 'like the Upper Thames valley, where there was a pattern of intensive settlement without apparent dependence on or direct relationship to hillforts' (Harding 2012: 270). The hilltop enclosures of Wales have received a measure of attention but despite being part of the hillfort-dominated zone are seldom considered together with the South Central evidence. Wales is unique for being wedged between the hillfort zone and the region of the Atlantic West (Henderson 2007a, 2007b), each of which representing vastly different building traditions and likely thus differing social practices. Other large scale erections such as the cliff castles of Cornwall, the promontories of southwest Wales, and the brochs of Atlantic Scotland might be said to fulfil a similar social role but are not the same edifices. Moreover, in the regions where hillforts are largely absent we find of a variety of domestic architecture types including the fen-edge settlements of the East (Evans 1997, Pryor 1984) and the larger agglomerated settlements of East Yorkshire alongside substantial inhumation cemeteries (Cunliffe 2005, Giles 2007b, 2012). That said, even within the *de facto* hillfort zone there is heterogeneity in domestic architecture and land enclosure practices.

Whilst we can acknowledge these differences at a superficial level it is often difficult to fully investigate the nature of settlement across such a broad region. We are constrained by access to sites largely gained through large scale development projects (*i.e.*, pipelines, quarries, *etc*). These excavations though undoubtedly useful are not designed around academic questions and therefore only allow us particular windows onto past occupations as they intersect with modern needs.

The South Central region of Britain remains the most excavated and analysed area for the Iron Age and prehistory in general. Whilst some like Cunliffe (2005) have endeavoured to give an account of the period for the whole of the British Isles, others such as Sharples (2010) have been perhaps more realistic in focusing solely on the southern region where excavations have produced the most exhaustive picture of Iron Age occupation in Britain. In contrast Harding (2004, 2006) has chosen to look strictly at northern Britain, highlighting some differences between the North and South, but focusing mainly on the unique settlement record observed above the Trent.

Though the examples highlighted herein have been used to illustrate a preoccupation with space and enclosure within Iron Age communities, these practices were by no means uniform nor necessarily widespread temporally or spatially. These examples of houses and larger enclosures have been chosen to demonstrate the increasing emphasis placed upon space within the period that is visible in the archaeological record. Further we must be careful not to focus on the boundaries as symptomatic of increasing competition or fear of warfare (*cf.* Darvill 1987, Hawkes 1931). Bowden and McOmish (1987, 1989) note that the boundaries of settlements, rather than serving as simple functional barriers, become a new arena for what can be termed 'excessive monumentality', as they bear physical witness to the conspicuous consumption of resources by individuals in later prehistory. Giles (2007b: 111) reminds us that boundaries 'do not in themselves create distinctions or define difference, but rather create the conditions in which difference can be performed'. Thomas sees the increased emphasis on boundaries and enclosure of the first millennium as evidence of 'changing kinship relations which placed a stronger emphasis on an 'insider'/'outsider' distinction' (1997: 215, *cf.* Sharples 2010: 3). Rather than focusing on the boundaries themselves, it is useful to instead shift our attention to the circumstances of their construction; human labour, a valuable resource, was located in the nascent communities, and needed to be called upon for the building of enclosures, linear ditches, and pit alignments (Sharples 2007, Sharples 2010, Bowden and McOmish 1987). Many hillforts were neither extensively nor continually occupied and the ramparts and entrances associated with them could only have been constructed by labour drawn from outside the hillfort itself (Cunliffe 2005, Payne *et al.* 2006, Sharples 1991, 2010).

> *'Human labour is a gift, which creates obligations. This gift can be clearly seen in the coming together of individuals in acts of communal construction' (Sharples 2010: 94).*

Gifts rather than commodities serve to bind individuals in obligation, in this case to the community as a whole (Godelier 1999). The communality revealed by the hillforts' construction can be witnessed in another site type unique to later prehistory: the midden.

Consuming Practices

The sites of Potterne, East Chisenbury, and All Cannings Cross in North Wiltshire, as well as Balksbury Camp in Hampshire, and Runnymede Bridge in the Thames Valley all show evidence of the large scale conspicuous consumption of sheep, cattle, and pig (Gingell and Lawson 1985, McOmish 1996, Cunnington 1923, Wainwright and Davies 1994, Needham 1991). Though these sites had nowhere near the imposing presence of the hillforts, neither were they invisible. The copious manure—an inevitable by-product of the animals brought 'on the hoof' to the sites for consumption—was not used to enrich arable lands. Rather, this refuse was 'allowed to build up to form low mounds—middens—, which subtly changed the local topography... provid[ing] visible evidence of excess' (Giles 2007b: 31).

Waddington (2009) presents the most comprehensive review of the first millennium BC phenomena of middens in Southern Britain. Her thesis details thirty sites across multiple counties, though largely focused on the area of Wiltshire, that present evidence of black burnt earth accumulations of organic matter and associated material culture. Waddington notes that though the environs in which these sites are located are varied the majority appear to exist at 'the junctures of different environments, with excellent views of the local environs' (2009: 6). Like the land boundaries mentioned earlier, these sites appear to serve to highlight the extents of communities acting as places of coming together for diverse groups across the landscape.

The midden sites, which stand as testament to the increased importance of commensality, appeared at a time when the ceramic repertoire was dramatically changing. The Middle Bronze Age of Wessex and the Southeast was dominated by Deverel-Rimbury wares, common in funerary contexts. The Deverel-Rimbury urns, originally thought to have been introduced into Britain by Hallstatt immigrants (or invaders) due to Continental parallels, later gave way to the aptly named post-Deverel-Rimbury plainwares (Cunliffe 2005: 9, Barrett 1980, Cunnington 1923). Whilst urns and buckets predominated the forms of the Middle Bronze Age and the beginning of the

Late Bronze Age, nearer to 800 BC (*i.e.*, the so-called 'great divide), a shift in the typical ceramic forms was observed. The ceramics of the late second millennium were predominantly concerned with storage of foodstuffs—as well as the dead. In the Late Bronze Age there was a diversification in shapes and sizes—in particular smaller vessels such as cups and bowls appeared. The appearance of new ceramic forms alludes to another facet of the changing behaviours illustrated by the middens. According to Barrett these new forms, as well as an increase in the deposition of ceramics in domestic contexts, were indicative of 'changes in the idea of what constituted the correct artefact for certain functions, including vessels used in one major area of social exchange, eating and drinking' (1980: 313-314). The increase in small vessels such as cups and bowls showed a shift in focus from storage of food to consumption (Barrett 1980: 311, 1989a). Both of these changes can be seen as characteristic of a more communally orientated culture in which food was consumed in co-presence. However these middens were only present as a site type until around 600 BC and do not represent a lasting change in practices (Brück 2007).

After centuries of post-Deverel-Rimbury plainwares in southern England, a decorated tradition appeared in Wessex of haematite-coated pottery bowls (Barrett 1980, Cunnington 1923). These bowls with their reddish lustre produced by iron-rich slips paid homage to the two materials held to define the periods of later prehistory: bronze and iron (Middleton 1987). When newly produced and burnished, the bowls would have closely mimicked the colour and sheen of beaten bronze, and the shapes do in some way resemble bronze vessels (Cunliffe 2005). At the same time the key ingredient in their decoration—iron ore—revealed a connection to the emergent iron production of the period—potentially even at the bowls' eponymous site of All Cannings Cross where reports of significant slag scatters were made (Cunnington 1923).

Perhaps most interesting for the scope of the present work are the numerous discoveries of the debris of bronze metalworking within the detritus of these midden sites, providing an intriguing link between this waning technology with this temporally and spatially constrained social practice equally concerned with performance and social *caché*. The increased diversity both in shapes and regional styles of pottery in the EIA has long been remarked upon (Barrett 1980, Cunliffe 2005, Needham 2007). However, Needham sees this increasing diversity in ceramic repertoire as the 'heir apparent' to bronze in later British prehistory, in terms of its role as the new currency for mediating social relations between groups (2007: 55-58). The evidence presented by Waddington (2009) of practices at midden sites shows as greater fluidity in this transition from bronze to ceramic for mediating social interactions. This transition appears to have been negotiated via conspicuous performance and consumption at these sites at points of transition themselves in the environment. The middens were showcases for the new repertoire of ceramic shapes as potters transitioned from large communal storage vessels to individual eating and drinking vessels ideal for commensality. Perhaps the middens represent only a short lived phenomenon in British prehistory for this very reason. They served their purpose of successfully shepherding a transition from a continental bronze focused culture to a more insular ceramic orientated one.

Metals in the First Millennium

The end of the Bronze Age was as much defined by bronze as the beginnings of the Iron Age were not by iron. Bronze was the currency and 'glue' of society at the end of the second millennium BC and early centuries of the first; traded, hoarded and ultimately deposited, sometimes in vast quantities, in a conspicuous manner to gain prestige and status (Bradley 1998, 2007, Needham 2007). Despite having viable copper and tin sources within the British Isles—the former were exploited in the Early Bronze Age—during the Middle and Late Bronze Age chemical analysis reveals that much bronze was imported from the continent as scrap or ingots, or even finished items, to be melted down and cast in British styles (Mighall and Chambers 1993, Northover 1982, Rohl and Needham 1998, Timberlake 2001, Ixer and Budd 1998, Parker Pearson 1993: 110). Additionally, some locally produced bronzes of the Late Bronze Age, for example many of the Carp's Tongue complex metalwork, slavishly copy continental examples (Parker Pearson 1993: 116, Needham 1990). However, in the first millennium there was a potential shift in focus and a return to the exploitation of domestic resources in the form of the copper sources in the southwest of Britain that are used in the production of Llyn Fawr metalwork (Rohl and Needham 1998).

Despite bronze being almost endlessly recyclable, a great deal of metal entered the ground as hoards or votive deposits, 'never to be recovered or recycled' in the Late Bronze Age (Barber 2003: 43, Bradley 1998). At the close of the Late Bronze Age in eastern Britain, this practice of bronze deposition reached its apex. During the period of 1000 to 800 BC, corresponding with the Ewart Park tradition, the amount of bronze entering the archaeological record was roughly five times that of the 'previous years of Penard and Wilburton' (Needham 2007: 53). For Needham, this upsurge in discard, which pointed towards the declining value of bronze as the social currency, occurred at 'precisely the time when Decorated [pottery] assemblages were beginning to emerge' (2007: 55). Needham sees this shift in emphasis away from bronze and towards ceramic as a renegotiation of how groups valued mediums for symbolic expression.

Throughout the Bronze Age the predominant manner in which bronze items were produced was through the utilisation of increasingly complicated moulds, constructed of ceramic or stone (Barber 2003, Tylecote 1986). Oftentimes, these moulds represent the only evidence of metalworking on a site (*e.g.*, Springfield Lyons, Essex and Norton Fitzwarren, Somerset), yet they are able to give an indication of the methods of production and level of control the metalworkers had over their craft—especially useful when furnace structures are particularly elusive for this period (Buckley and Hedges 1987, Ellis 1989, Tylecote 1986). Around 1000 BC leaded bronzes began to be produced, giving the metalworkers the ability to work at lower melting points and to cast more complex forms (*e.g.*, long flat swords), with greater ease (Darvill 1987, Tylecote 1986). By the end of the Late Bronze Age, a new method of working bronze surfaced in Britain and introduced a way of engaging with metal involving the hammering of bronze into sheets that could then be riveted into elaborate shapes. This technique, only previously used for some gold items, would be important as iron required percussive forging rather than the casting of a melt, to produce finished objects (Barber 2003, Tylecote 1986).

The first non-imported iron item in Britain is generally accepted to be a sickle found in a hoard at Llyn Fawr, Glamorgan, along with other pieces of bronze metalwork, dating to the eighth century BC (Savory 1976). The sickle is believed to have been locally produced as it copied a local bronze form. At around the same time, indications of the first iron smelting come from the southwest in Devon and Cornwall, later spreading north and east into southern England (Fox 1954a, 1954b). This proliferation of iron production over broad territory was accomplished in part through the widespread availability of iron ore. Though there are three commonly cited large ore deposits for Britain—the Forest of Dean, the Jurassic Ridge of Northamptonshire and Lincolnshire, and the Weald—Ehrenreich (1991) has noted that iron ore is present and readily available in virtually every modern county. This ubiquity of iron ore is in stark contrast to the isolated nature of the copper and tin deposits necessary for bronze production.

For Childe (1942), iron was the democratising metal. The diffusion of iron metallurgy was initiated by revolting low class Hittites who spread the technology to Europe (Childe 1930). His model was one of simple cause and effect—a bronze shortage prompting necessary technological evolution in the form of iron metallurgy—the ubiquity of iron ore deposits meant, to Childe, that iron democratised metal production rather than it being reliant on isolated copper deposits and the associated trade networks. Other explanations of change have chosen to focus primarily on the varying role of metals as evidenced through deposition. Shifting patterns of elite consumption of bronze goods, as witnessed in depositions, are taken as an indication of a collapse in the power structure of Late Bronze Age society (Thomas 1989, Bradley 1988). This collapse was potentially initiated by a breakdown in the exchange networks associated with the import of exotic and prestige goods. 'The transition is not so much about replacing bronze with iron, but rather, doing away with a *social value system* based heavily on bronze' (Needham 2007: 58). The emergence of iron in Britain may have been contemporaneous with this event, but was surely not its cause. Indeed as Bradley suggests 'perhaps iron could not be treated as a substitute for bronze 'because these two raw materials had different *meanings* for those who used them'' (Bradley 1998: xxx). The significance of the two metals can ideally be revealed through the careful study of the contexts of their production.

METALWORKING: PRODUCTION AND PRACTICE

By the Middle Iron Age some indication of iron smithing was found at virtually every settlement site (McDonnell 1982, Salter 1989, Ehrenreich 1985, 1991). Unfortunately, well-documented evidence for iron production—primary or secondary—is much more limited (*cf.* Brett *et al.* 2004, Collard *et al.* 2006). Iron metallurgy appeared to be a common practice across Britain—although it varied greatly in scale and character; in contrast, the working of copper-alloys was considerably less common. With the pervasiveness of such practices and their associated residues, comes a disregard for the material and associated contexts in the written report. Whilst the ubiquity of iron smithing across Iron Age settlements is relatively easy to establish, we can rarely comment on the precise actions involved in the activity or its specific context of practice. Simple methods do exist to establish if metallurgical practices extended to non-ferrous materials or were restricted to ferrous (Bayley *et al.* 2008). However these methods are rarely employed, with excavation reports often only detailing diagnostic debris forms, *e.g.*, plano-convex slags—'smithing hearth bottoms' (McDonnell 1983, 1986). Rather than analysing the techniques and contexts of practice that produced these residues of practice, more effort has been expended on recognising scale of production—symptomatic of a desire to find evidence of specialisation in metalworking (*i.e.*, permanent or itinerant smiths) (Childe 1941, Ehrenreich 1991). Equally, with the contexts of production, basic excavation techniques can easily record hammerscale density and reveal detailed insights into the use of space, but such is rarely undertaken (Veldhuijzen 2009a, Jouttijärvi 2009). It becomes clear then that Iron Age ferrous metallurgy, as well as copper-alloy metallurgy (which has been dominated by research into alloy compositions (Dungworth 1996, Northover 1988)) is widely acknowledged, but severely understudied, leaving us with little real insight into regional variation or even site specific practice. It is convenient to consider all practitioners of iron or copper-alloy metallurgy as united from a contemporary chemical perspective, however such a unifying category would have been meaningless to them and no doubt even less so for how such practices are accommodated within local traditions.

The work of Melanie Giles (2007a, 2007b, 2012) in particular her paper from 2007 '*Making Metal and Forging Relations*' has excelled at emphasising the multifaceted nature of metalworking practice in Iron Age Britain. Whilst many authors in the 1980s and 1990s focused on the practical aspects of metalworking (*e.g.*, McDonnell 1986, 1988, Crew and Crew 1995), attempting to identify sources of raw materials and models of primary and secondary production within ironworking communities, Giles has chosen to embrace the wealth of information gleaned about modern non-industrial metal production from ethnographic studies in Africa, India, and beyond. Building off the work of Ehrenreich (1985, 1991, 1994) which dispelled the notion of hierarchical production within Iron Age communities, Giles extends his heterarchical model to explore the multiple roles of those involved in the secondary production of iron and copper-alloys. Giles is right to point out that metalworking represented one of the few non-seasonal activities undertaken by Iron Age individuals and therefore in a society defined by agricultural production cycles, metalworking could be viewed as an activity that transcended the typical bounds of sowing and harvest cycles (Giles and Parker Pearson 1995, Giles 2007a). Further she demonstrates quite convincingly that the actions involved in metalworking from the prospecting of ore, to beneficiating, to smelting, *etc* could all be seen to mimic or have parallels in agricultural activities (Giles 2007a, 2012). In a way tethering metal production to the land and emphasising its role in metaphorically cultivating the continual fertility of (metal) products and (plant) produce. Metalworking could been seen as a radical activity of the land giving birth out of season, even in the depths of winter. Those individuals who could harness such a power would surely be revered or at least wondered at within these Iron Age communities. As the level of metalworking evidence recovered from Iron Age sites remains quite low, the idea of permanent smiths or metalworkers is difficult to sustain. It becomes intriguing to hypothesise as to what additional roles these individuals might have held within their communities and whether or not they were equally performative or mystical in nature.

The relative paucity of obvious large scale iron production sites for much of the British Isles supports the idea of heterarchical production at even the primary level of production. Sites such as Crawcwellt (Crew 1989, 1990, 1995, 1998), Trevelgue Head (Dungworth 2011), and Welham Bridge (Halkon and Millett 1999) are exceptional—in all senses of the word—and certainly could not have served the whole of England and Wales. Moreover, the widespread availability of iron ore in all of the modern counties of Britain (Ehrenreich 1985) supports the idea of highly dispersed localised production of iron as needed by communities.

Whilst largely in agreement with the ideas put forth by Giles about the roles played by metalworkers and metalworking in Iron Age communities, the focus of this work is less on the *practitioners* of these crafts than the detectable traces of their *practices* captured in the contexts where they worked. The work of spatially analysing the actions of past practitioners can neither confirm nor deny ideas of heterarchical or hierarchical production when looking at individual sites. But as we begin to build up a database of information gleaned from the geochemical and geophysical analysis of contexts of production we can attempt to isolate settlement wide or even regional patterns and/or similarities in practice (See Chapters 8 and 9 for what we will term ‘communities of practice’) that have the ability to interrogate these theories of the organisation of Iron Age metalwork production.

Giles is ultimately interested in identity. She sees the roots of identity in practice. I concur that identity is forged and re-forged through practice. However I am not certain if practice can be excavated in such a manner as to inform upon identity at anything but the broadest level. In Chapter 6 it is demonstrated that individuals are not readily apparent in the remains of metallurgical practice, instead it is the cumulative residues of individuals actions—in essence their accumulated agency—that can be excavated.

Ultimately, this reveals a great deal about past actions but tantalisingly little about past actors.

Primary Production

Evidence of sites with actual furnace structures for iron smelting in Early Iron Age Britain is scarce. Experimental production of iron reveals that the upper portion of furnaces, though substantial structures, rarely becomes vitrified during smelting, and is therefore subject to rapid degradation outdoors (Young n.d.). Thus it is not surprising that these structures remain elusive and/or poorly reported, yet there are other ways of proving smelting occurred without evidence of the actual architecture of production. In particular, McDonnell's (1986) unpublished thesis, on the classification of iron working slags, details common compositions of smithing slags and gives succinct criteria for the separation of smelting from smithing slags.

The site of Kestor in Devon appears to exhibit the earliest evidence of iron smelting in Britain. A bowl furnace 'choked with iron slag', iron ore from a local source, and a broken anvil were found within this settlement of agglomerated houses on Dartmoor, generally dated to the Iron Age around the fifth century BC (Fox 1954a: 95). Also in the southwest of Britain, the promontory site of Trevelgue Head in Cornwall, dating to the second half of the first millennium BC, offers some persuasive evidence of furnace bases. Whilst these remains are not conclusive, the volume of smelting slag recovered (almost 200kg) points towards primary production of iron at the site (Dungworth 2011). All Cannings Cross in Wiltshire presents some of the most tantalising evidence for iron smelting in the form of tap slag (Cunnington 1923). This type of ropey slag is produced when the molten slag from the smelt is allowed to run free of the furnace and represents an advancement in furnace 'technology' from earlier bowl designs (Tylecote 1986: 132-139). This find is remarkable in that the site dates to very beginnings of the Early Iron Age, while tap furnaces are generally not accepted to have been utilised until the Later Iron Age (Cleere 1976).

Brooklands in Surrey is an early iron production site that remarkably has preserved evidence of at least five smelting furnaces. The remains appear to be bowl type furnaces, yet Cleere (1977) argues that based on the slag produced they are more likely simple non-tapping shaft furnaces. More interestingly, the site has two spatially distinct areas of metalworking: one more associated with smelting; and the other focused on the secondary working of the metal. The cave site of Rowberrow Cavern in Somerset provides further evidence of smelting in the Early Iron Age, around the middle of the first millennium BC, in the form of apparently partially smelted ore, slag, and charcoal (Taylor 1926). There were no furnace remains, but the slag has been examined more recently and declared to be the product of smelting (Paynter 2006).

The recoverable evidence of iron smelting in the first millennium is not always small scale. In North Wales, at the site of Crawcwellt, Merioneth, dated to later than the fourth century BC, excavators encountered a staggering ten tonnes of iron smelting slag along with the remains of five or six furnaces (Crew 1995). The site of Bryn y Castell, though of a later date in the second century BC, produced over a tonne of smelting slag, as well as a unique snail-shaped enclosure possibly associated with smithing (Crew 1987, 1988). Survey and excavations on Holme-on-Spalding Moor in East Yorkshire have revealed evidence of an intensive iron industry during the first millennium BC, encompassing over fifty sites (Halkon 1997). One particular site of Welham Bridge produced over 5000kg of slag, dated to the middle of the first millennium BC, though no direct evidence of furnace structures remains (Halkon and Millett 1999).

At present, there is little to connect these sites other than their obvious primary production of iron. Settlements were varied in type from small enclosed homesteads (*e.g.*, Kestor), large defended hillforts or promontory sites (*e.g.*, Trevelgue Head), and open settlements (*e.g.*, All Cannings Cross and Welham Bridge). Whilst it is the upland enclosed site of Crawcwellt in North Wales that has produced the greatest evidence of iron production in later prehistory, the open settlement site at Welham Bridge in East Yorkshire demonstrated iron smelting on a similar scale. At the same time, the other ‘fort’ site of Trevelgue Head produced less than five percent of the total slag found at either of these sites. Whilst we can make comparison between the settlement contexts and estimated scales of production, without an analysis of the actual practices which occurred at these sites—and their resultant residues—our conclusions will remain necessarily vague. Industrial models of production cannot be imposed onto evidence and Ehrenreich (1991) has aptly noted the non-hierarchical state of iron metallurgy within the Early Iron Age, using the term heterarchy to describe the heterogeneous archaeological record for the period. We must utilise more nuanced analytical models to interrogate the archaeological record, in order to reveal the signatures of past practices preserved in these production contexts.

Secondary Production

As mentioned previously, iron smithing occurred regularly on sites during the Iron Age, albeit on a relatively small scale (Salter 1989). Many settlements produce a few kilograms of slag, but as this material is often deposited in pits, it is difficult to identify, and more importantly examine, the actual arenas of production (Ehrenreich 1991). Only careful excavation of settlements, in particular those that have not already suffered from truncation, can help to reveal more of the spatial constraints of past iron as well as copper-alloy working.

Copper-alloy working, in contrast to the evidence for iron smithing, is relatively uncommon, though when it evidenced it is often on a large (possibly industrial) scale. The two sites of Gussage All Saints, Dorset and Weelsby, South Humberside produced evidence for intensive manufacture of cast-bronze horse equipment (Spratling 1979, Wainwright and Spratling 1973). Gussage All Saints generated over six hundred crucibles as well as 7000 fragments of moulds, whilst Weelsby had over 3000 mould fragments (Foster 1980, Foster 1995). Interestingly, at Gussage All Saints the was small scale working of iron contemporary with the bronze casting, similar to that evinced on other sites of the period. Thus, even within a single site, the scales and contexts of these two metallurgical processes are markedly varied. Aside from these examples of large scale bronze casting, the sites of Glastonbury and Meare Lake Villages each produced evidence of copper-alloy working in the form of numerous crucibles, but limited slag, as well as some limited indications of ferrous metallurgy, leaving the excavators to suppose that the casting occurred away from the settlements (Bulleid and Gray 1911, Bulleid and Gray 1917, Bulleid and Gray 1948, Gray and Bulleid 1953, Gray 1966). Lastly, the site of Maiden Castle, well known for its conspicuous iron production at its entrance in the Late Iron Age, contains evidence of contemporary iron smithing and bronze sheet working within the same spatial contexts during the Middle Iron Age (Wheeler 1943, Sharples 1991). The frequent co-presence of copper-alloy and iron working on these sites requires a more nuanced approach to the analysis of these interconnected practices. The difference in scales and distribution of practice cannot be examined through artefactual debris alone. An exploration of the contexts of production has the capacity to reveal patterns, or *signatures*, in the residues of practice, which can ultimately illuminate the interrelatedness of these past activities.

SUMMARY

The changes in social practices witnessed in the first millennium in Britain reveal a profound investment in space evidenced both in material remains and human labour. The two are inextricably linked through the medium of human action. The enclosures, boundaries, settlements, and structures of the Iron Age are the enduring reminders of the labour invested in specific places. As communities became more established, the impact of their collective actions in turn became more visible, in the form of hillforts and extensive networks of land enclosure. Yet, what is less clear is how at the scale of people and practices, these communities served to construct and enfold the world around them—creating the spaces evinced in the archaeological record. Within these communities existed craft practitioners such as the metalworkers alluded to above. Metalworking is one such social practice that is capable of revealing itself both through its debris and the results of labour invested. Whilst the evidence for the period is certainly not homogeneous, past approaches to metalworking have focused on broad stroke narratives subsuming the observed variation. In these narratives the practitioners of metallurgy are invisible, replaced by equations and operating constraints. However, the processes involved in bronze and iron metallurgy cannot be classified as simple technical or chemical processes, but rather are both social and situated and can be studied in a more contextualised manner in order to reveal how they relate to the broader communities seen in the period. At the local level of production—at the human scale—we need to examine space and inhabitation, to unearth distinctions in residues and signatures of practice. Only once this evidence is gathered can these examples be used to create a mosaic of understanding—an awareness of *communities of practice*—that might be useful for providing the super-regional narratives that some Iron Age specialists once again seem desperate to write.

Chapter 3. Crafting space

INTRODUCTION

> *'Craft is another name for responsible and skilled work. The responsibility is to that balance of inward and outward need which is life itself.' (Leach 1945: 49)*

Perhaps we should begin with a rather radical statement: *craft* has nothing to do with *things*. It is easy to quickly dismiss this proposition, but a simple deconstruction of this claim can be revealing. Craft has been predominantly studied through objects, yet, craft is *not* objects, and cannot be understood through their study alone. *Craft* and *crafts* have been conflated in common parlance. Craft is not the *product*, the artefact, the object; rather it is the *process* of its production (Whitehead 1927, Dobres 2000). Craft is the purview of people. Frequently, when craft is addressed archaeologically it is done so as a post-excavation activity where artefacts have already been severed from their contexts and creators (*e.g.*, Foster 1980, Howard 1991, Salter and Northover 1992, Middleton 1987). In this state, objects are thought as being *with* context rather than *in* context.

This chapter therefore seeks to establish and review the changing relationships that archaeologists and social theorists have developed with space, place, and the environment through the lens of the study of craft production. *Craft* is often used in archaeological texts as the precursor to industry. It suggests a domestic scale of production for personal use or to be exchanged in local networks (Costin 1991, Budd and Taylor 1995). This denotation of craft ignores the crucial bodily aspect of both ancient and modern craft practice. Many contemporary understandings of technology think of machinery separating 'man' from the production of even the most basic items, while past craftspeople are seen to be intimately acquainted with the creation of their wares through the media of their own hands and bodies (Pfaffenberger 1992, Ingold 1988, 1997).

Ingold and others have argued for the idea of *Homo faber* rather than *Homo sapiens* (Ingold 1986). In this way, it is apparent that all humans are engaged in craft of some form by virtue of *being-in-the-world* (Heidegger 1962, Gosden 1994). The concept of craft implies the gerund (*i.e.*, craft-*ing*), making it conspicuously active and engaged. Moreover the idea of craft used herein is not in opposition to industry, as is often noted in themed histories of artefact production, but rather serves as an alternative. This retreat from the craft/industry concept of progression, challenges us to view craft not as a proxy for complexity, but instead as a completely socialised practice.

At the heart of craft is *tekhnē,* ‘a general ability to make things intelligently’ (Bruzina 1982: 167, Ingold 2000). Craft is the translation and transformation of that knowledge, tradition, and most importantly material, through bodily techniques. Many studies have endeavoured to address agency as it relates to craft production (Dobres 1995, 1999, 2000, Dobres and Hoffman 1994, 1999, Edmonds 1990a, Lemonnier 1993, 1992, Ingold 2000), yet these studies have concentrated on addressing issues of material selection and technical choices. For some decades archaeologists have afforded craftworkers choice, yet they have not routinely (or perhaps even occasionally) extended this concept of choice to space or the contexts, which support specific bodily practices. Edmonds was one of the few to have challenged this approach noting that it ‘effectively divorces the act of material production from questions of human agency, since it denies the web of social relations in which any technology is situated’ (Edmonds 1990b: 28). These social relations are necessarily situated, and this exclusion of space from the repertoire of technological choice has resulted in the skilled crafter being somehow dislocated from the world, capable of exercising a myriad of material and technical choices yet somehow abstracted from the fully recognisable practice. This is important as it suggests strongly that concepts of space in contexts of craft are a generally untheorised, and hence underdeveloped, aspect of technology studies.

All craft production is situated in the world, and at the very heart of craft production is the individual creating him or herself, the *skilled knowledgeable agent*, versed in techniques of the body that animate whatever craft they practice (Barrett 2000). Individuals, agents or otherwise, are permanently enmeshed with the world (Ingold 2000, Barrett 1988, Heidegger 1962). Their existence is inseparable from time and space, thus any attempt to speak of agency in relation to craft or other activities would do well to acknowledge the role of space as a major constitutive element of agency. Though space is abstractly acknowledged archaeologically through contexts of production, a critical interrogation, or even a basic understanding, of space is notably lacking from the majority of craft studies. If we are to assert that space is a critical constituent of agency, as will be explicated in great detail below, without considering space, no claim to an investigation of the agency of craft production can be upheld.

TIME AND SPACE

A study of craft must have a beginning, or more *apropos*, a context. All craft is necessarily situated in time and space, yet these universal notions have myriad connotations. The modern concept of time/space is convenient and seemingly simple with its origins in the famous epistolary debate between Isaac Newton and Gottfried Leibniz (Clarke 1717). Newton, as represented by Clarke, argued for a Cartesian view of 'absolute' space that pre-exists individuals and objects, whereas, Leibniz conceived of a 'relational' space that comes into being through interactions. Kant (2003) has also argued for the *a priori* existence of time (*i.e.*, a 'realist' position that advocates for time and space as existing independent of our perception of them). This *a priori* conception of time and space is directly opposed to the 'relational' view—advocated for by Leibniz as well as Heidegger (1962)—that space and time unfold around individuals as they go about their lives and become *real* only through our relationships with others. Thus, directly challenging popular approaches that treat the space as an ever-present backdrop waiting to be filled with objects and events and time as a constant ever-flowing entity detached from the ebb and flow of human action. The relational, rather than the absolutist, view provides greater potential for the exploration of the spatial dimensions of craft, acknowledging the active role individuals have in creating the world they inhabit (Lane 1994).

In-the-World

An understanding of Heidegger's conception of time and space is always complicated by the labyrinthine nature of his terminology. 'Space' for Heidegger is distinct from the common Cartesian understanding and has seemingly informed a number of recent reappraisals of how practice is considered, for instance it is at the heart of Giddens' ideas of regionalisation (Giddens 1984, 1985), Ingold's concepts of wayfaring and meshworks (Ingold 2011), and Barrett's *fields of discourse* (Barrett 1988).

> 'Space is not in the subject, nor is the world in space. *Space is rather 'in' the world in so far as space has been disclosed by that Being-in-the-world which is constitutive for Dasein' (Heidegger 1962: 146).*

For Heidegger time/space is in actuality time/*world*, for space cannot pre-exist the world. His space is not a plane, but rather an arena, or perhaps more aptly a medium, of connections. Space affords Dasein's (*i.e.*, literally 'being there' or 'presence', at the basest level, the seat of existence of an individual) actions, observing that '[w]hen we let entities within-the-world be encountered in the way which is constitutive of Being-in-the-world, we 'give them space'' (Heidegger 1962: 146); yet that space does not locate those entities in a typical positional sense. Therefore if we are to take a Heideggerian approach to time/space and the contextualisation of craft, this conception should be replaced with a more apt term. To follow Heidegger, *world* is the most appropriate word for the meaning conveyed in the ubiquitous time/space notion. World is Heidegger's container for action; the arena in which individuals actually produce space. It is the setting which affords all behaviours that we would consider to be situated in space and time. However, world itself has its own faults as a term due to its own myriad connotations in English. Instead, we propose the use of *Welt* [world], to signify the realm of potential interactions in the following discussion. Whilst *Welt* remains an important aspect in our discussion of agency, it signifies the arena of agency's actions, rather than a productive component of agency itself. The idea of time and space that Barrett (Barrett 1988, 1994b, 2000, 2001) as well as Giddens (Giddens 1979, 1984, 1985) reference in their discussions of agency is captured instead in Heidegger's concepts of temporality and spatiality which reveal the means by which individuals are able create and recreate their settings in copresence with one another.

Temporality/Spatiality

In discussing spatiality, Heidegger introduces the terms of *de-severance* and *directionality* that serve to describe how Dasein situates itself in *Welt*.

> *'Dasein is spatial in that it discovers space circumspectively, so that indeed it constantly comports itself de-severantly towards the entities thus spatially encountered' (Heidegger 1962: 143).*

There is no simple English translation for de-severance [*Ent-fernung*], which in its original German is most akin to the concept of remoteness. De-severance is best understood as the ability of Dasein's Being to make itself nearer or farther from another entity as they reveal themselves in *Welt*; '"[d]e-severing" amounts to making the farness vanish' (Heidegger 1962: 139). However, the nearness and farness of de-severance are *not* measures of distance, making the idea of de-severance well-removed from our Cartesian sensibilities. De-severance is the notion that all individuals and their actions are relational and can only be understood and appreciated in the context of one another. In the study of craft, the concept of de-severance can be used to address the manner in which individuals presence themselves (Pred 1984, Giddens 1984) both with other individuals as well as the equipment of production as they inhabit *Welt*. In contrast to de-severance, directionality is a markedly easier term to comprehend, and Heidegger thankfully uses it in a manner largely similar to that of the English word. Directionality is responsible for orientating Dasein's Being; situating it in *Welt*. Therefore, for

Heidegger the twinned concepts of de-severance and directionality are inherently *relational* rather than positional. This realisation of the nature of these concepts leads one to conclude that Dasein simply *cannot* exist alone. Consequently, Dasein is inherently a social Being. The spatiality of Dasein places him at the centre of a meshwork of connections and other Beings.

Heidegger enigmatically asserts that ‘'Dasein's Being finds its meaning in temporality’ (Heidegger 1962: 41). Temporality invigorates Dasein and makes his Being into a dynamic Being-in-the-world capable of traversing and exhibiting concern for *Welt*. His temporality is not an alias for time, but rather is ‘the foundation for that spatiality which is specific for Dasein’ (1962: 384). Heidegger’s language is unfortunately at his most oblique in discussing temporality, but it appears that as time is to space, temporality is to *Welt*—the totality of time in which action can occur.

> *‘The phenomenal content of this meaning, drawn from the state of Being of anticipatory resoluteness, fills in the signification of the term "temporality". In our terminological use of this expression, we must hold ourselves aloof from all those significations of 'future', 'past', and 'Present' which thrust themselves upon us from the ordinary conception of time’ (Heidegger 1962: 374).*

Two particularly useful concepts introduced by Heidegger for illustrating Dasein’s relational situation to others in *Welt* are *ready-to-hand* and *present-to-hand*. Readiness-to-hand is described as having the ‘*character of inconspicuous familiarity*’ and implies recognition through perception of entities as *qua* equipment in-the-world (Heidegger 1962: 137). Presence-to-hand, conversely, requires Dasein to determine an entity’s utility, often through the intermediary of other entities, chiefly equipment that is ready-to-hand. For those that follow the Cartesian model, the world, that is the environment or space, is present-to-hand, ready to be populated by individuals. Yet as shown above, the world never exists as such for Heidegger’s Dasein. As a Being-in-the-world, the world itself can never be less than ready-to-hand for Dasein. This is not to say that all entities and things in *Welt* are in a continual state of readiness-to-hand for Dasein’ Being, only that *Welt* as the locus, the situation, of Dasein’s Being can never not exist for Dasein and therefore can never be anything else other than ready-to-hand.

Conceptualising time/space as *Welt*—that is the situatedness of one in the world—has real effects on how we consider our analyses of craft space. The spatiality/temporality that replaces the typical understanding of the time/space aspect of agency (see below) is relational. Heidegger's space is how one inhabits, how someone places attention and intention to within the situational to establish a niche. *Welt* is situational, temporality/spatiality is relational, but space—space is created only in *Welt* and only through the establishment and maintenance of relations. Space as a Heideggerian concept is fully in-the-world. It is *in Welt,* and thus is not static and can be moulded and manipulated by those who inhabit it. Space is the domain of practice; the dwelling of craft, in essence *Umwelt* [around or about the world, setting, environment] (*cf.* Merleau-Ponty 2002: 100, Ingold 2000). If space can be associated with *Umwelt,* then it is only through acknowledging that it is only realisable through its creation in *Welt*. *Umwelts*, or spaces, then can be thought of as being a product of agency as it is crafted through practice. This premise offers great potential for craft studies, and again serves to defocus current studies from the material processes with which craft is so often simplistically associated. While it is widely acknowledged that craft produces more than things, for instance the identity of the crafter (Dobres 2000), recognition of Heidegger's approach to space indicates that through craft very particular types of *Umwelts* are made and inhabited within the world. For archaeologists this can be thought of as manifesting, in part, in the spaces and the material patterns with which we associate particular types of practice. Significantly, they can be thought of as being as instructive about the habits of craft as the materials and *things* with which our studies are normally preoccupied. From this perspective we can begin to see space, in the Heideggerian sense, as having the capacity to reveal agency. For Heidegger, it was his Dasein that was the seat of agency, and it was its de-severance and directionality that could have the ability to draw upon tradition (memory), materials, and *Welt* to act through/as Being in *Welt* in order to create and recreate *Umwelts*.

Giddens was among the first to take forward the idea that all social action is inseparable from time and space, in a method of sociological analysis that addressed patterns of practice as they extended through time and space (Giddens 1979, Giddens 1984). In noting 'most forms of social theory have failed to take seriously enough *not only the temporality of social conduct but also its spatial attributes*' (1979: 202) Giddens embarked upon a project that insisted in situating sociological analysis in the world. When discussing the contexts or arenas in which action, the medium of structuration, transpires, Giddens remarks '[b]y the term 'context' (Goffman prefers that of 'situation') I mean those 'bands' or 'strips' of time-space within which gatherings take place' (1984: 71). His idea of context is somewhat analogous to Barrett's material contexts (Barrett 2001), similarly indicating a bounded or delineated space in which relations between individuals are played out.

Ingold (1993, 2000) is noted for his critical assessment of sociological and anthropological literature and in highlighting how many studies have used ideas of space in an unsophisticated manner as the passive backdrop upon which lives are built. In forwarding a counter position, Ingold further develops his ideas of a *dwelling perspective*, which

> *'treats the immersion of the organism-person in an environment or lifeworld as an inescapable condition of existence. From this perspective, the world continually comes into being around the inhabitant, and its manifold constituents take on significance through their incorporation into a regular pattern of life activity' (2000: 153).*

Ingold's idea of the lifeworld seems rooted in Heidegger's own views of world and worldhood, or *Welt*. The lifeworld for Ingold provides an environment in which 'cultural knowledge' (*i.e.,* the structuring principles of Giddens or the tradition of Barrett) does not exist independently, but instead

> *'is constituted within these settings through the development of specific dispositions and sensibilities that lead people to orient themselves in relation to their environment' (Ingold 2000: 153).*

The settings of which Ingold speaks have much in common with the *fields* of Barrett (1988) and *Umwelt*, discussed throughout. They are areas of the world, of *Welt*, in which people have actively created meaning. Ingold has constructed his dwelling perspective, much in line with Barrett's own 'archaeology of inhabitation' (2000), in opposition to what he views as the dominant viewpoint of the building perspective, in which he feels that 'the earth is presented to humanity as a surface to be occupied rather than a world to be inhabited' (2000: 155). The dwelling perspective of Ingold further reinforces our conception of the world as revealing itself through the situated actions of inhabitants.

CONSCIOUSNESS AND PERCEPTION

Central to the idea of how the world is made are the notions of consciousness and perception. There are competing psychological and neurological paradigms of the nature of consciousness that are diverse, challenging, and often incomplete. The unfinished nature of these projects presents problems to social theorists who aim to use them often as foundations of wider studies. From a biological perspective, unconscious actions are only those that do not involve the use of the cerebrum or cerebellum in their execution (Bear *et al.* 2006). The most obvious examples of such actions are breathing, the beating of the heart, and reflexes, the impetus of which are based in the brain stem and the spinal column. Other actions that might potentially be considered unconscious (yet are not truly so) to a layperson such as walking or tying ones' shoes are directed by the cerebellum and are the result of repetitive or routinised use of neuronal pathways to develop so-called 'muscle memory', so that the actions can be performed without the involvement of the cerebrum (*i.e.*, the seat of thought and consciousness).

While widely researched across a number of disciplines, consciousness appears to involve the non-reptilian (*i.e.*, the most vestigial, from an evolutionary perspective) portions of the brain (Bear *et al.* 2006). However consciousness is not solely located in the mind, it involves an awareness of the self and the world. Consciousness is an undertaking in and of itself, the continually unfolding process of coming to terms with and creating the world (Merleau-Ponty 2002: x). Merleau-Ponty undertook an extensive study that tackled the nature of perception, and by extension consciousness, and drew heavily on both theory and the practical observation of a number of patients with psychological disorders. In addressing the issue of perception and the world, he presents a stimulating conception of the latter '[w]e must not, therefore, wonder whether we really perceive a world, we must instead say: the world is what we perceive' (2002: xviii). This view of the world harkens back to the idea of relational time and space that only come into being through our interactions with one another. Similarly, for Merleau-Ponty our environment is actively constructed through our perception of it. Further, perception is a situated understanding of sensory information. It is predicated upon knowledge and memory; only through experience are we able to comprehend the world.

Merleau-Ponty's usage of consciousness in concert with his ideas of the body is notably influenced by the work of Heidegger: 'consciousness is being-towards-the-thing through the intermediary of the body' (Merleau-Ponty 2002: 159-160, Heidegger 1962). Whilst Merleau-Ponty is able to explicate many of the nuanced biological and psychological underpinnings of consciousness, his conception of this matter fundamentally mirrors that of Heidegger's philosophical creation: Dasein. Merleau-Ponty proposes 'habit' as an intermediate existence, of sorts, between consciousness and movement.

> *'If habit is neither a form of knowledge nor an involuntary action, what then is it? It is knowledge in the hands, which is forthcoming only when the bodily effort is made, and cannot be formulated in detachment from that effort' (Merleau-Ponty 2002: 166).*

A tripartite model of consciousness is proposed, into which the concept of habit finds a natural home, borrowing both practical and discursive consciousness from Giddens.

This model is necessary to dispel the problematic proposition that unconsciousness is the same as being not conscious of something (*contra* Giddens 1984: 44); actual psychological unawareness of activity is only encountered in quite specific situations. We can be unaware of how we execute certain actions and be unable to break down the individual movements inherent (*e.g.*, walking). However, we are still aware that we are carrying out these actions even if we are unable to explicate fully how we do so. Consciousness is not perception or sensory awareness alone. Discursive consciousness is recognised by an individual's ability to know both what they are doing as well as why they do so (Giddens 1984: 45-49). Practical consciousness presents individuals that can explain what they are doing but not why, as the motivation is not at the forefront of their minds (Giddens 1984: 49). The term dis-consciousness is proposed to emphasise the middle ground occupied between unconscious action and complete unawareness, either of the actions themselves or more simply their motivations for doing them. It is put forward that this state of consciousness is often responsible for social continuity through the promulgation of habituated actions (*e.g.*, habit) and at the same time can also be responsible for actions related to a more overarching sense of intentionality that an individual is only tacitly aware of.

Further, there is a surprising distinction to be made between consciousness and conscious acts. An agent can consciously motivate an act that is then enacted in a state of dis-consciousness. What is commonly referred to as unconscious behaviour or action lies between practical and dis-consciousness. It lacks direct motivation, yet such 'unconscious' acts can be rooted in agency. For example, repeated crafting involves routinised behaviours, in which the individual does not need to think about how to go about certain activities. The overall project is part of motivated agency yet the discrete actions (*e.g.*, kneading clay, throwing on the wheel, pumping bellows, *etc.*) are commonly enacted in a state of dis-consciousness (*contra* Malafouris 2008).

DASEIN, BEING, AND THE BODY

> *'The body and consciousness are not mutually limiting, they can only be parallel.' (Merleau-Ponty 2002: 142)*

The body is the vehicle by which consciousness is able to inhabit *Welt* and thereby craft *Umwelt(s)*, '[w]e must therefore avoid saying that our body is *in* space, or *in* time. It *inhabits* space and time' (Merleau-Ponty 2002: 161). Turning to Heidegger, we can look at how the concepts illustrated in *Being and Time* directly relate to our discussion.

Heidegger challenged philosophers to cease writing on the nature of being and to learn to question what was actually *meant* by being (1962). At the simplest level, ‘Being is always the Being of an entity’ (Heidegger 1962: 29). Yet, for Heidegger *Being* refers not to the body alone, and is ‘taken as a unity of body, soul, and spirit’ (1962: 73-74). Being itself, can be said to possess another entity, *Dasein,* which is unique amongst other entities as ‘it is ontically distinguished by the fact that, in its very Being, that Being is an *issue* for it’ (Heidegger 1962: 32).

> *'That kind of Being towards which Dasein can comport itself in one way or another, and always does comport itself somehow, we call "existence" [Existenz].’ (Heidegger 1962: 32)*

Though necessarily simplified, one of the most basic distinctions to be made between Dasein and Being is that of existence and the medium or vessel of existence. Dasein is an entity that exists, yet only through Being and Being’s situation in-the-world. In an ominously titled section, ‘*The Task of Destroying the History of Ontology*’, Heidegger sets out to clarify the relationship between Being and Dasein.

> *‘Dasein's Being finds its meaning in temporality. But temporality is also the condition which makes historicality possible as a temporal kind of Being which Dasein itself possesses, regardless of whether or how Dasein is an entity 'in time'’ (Heidegger 1962: 41).*

In turning to our earlier discussion of the twinned notions of time and space we find that Beings are always situated and therefore understandable by virtue of being-in-time (Heidegger 1962: 39). However, situatedness carries with it the spectre of worldness and thus as all Beings are in-time, they are also in-the-world. Being-in-the-world is not indicative of entities against a static backdrop, a blank world waiting to be populated by entities. This being-in is more akin to situatedness or inhabitation. There is nothing Cartesian about this concept, Being-in-the-world does not equate to a corporeal entity and its location in a realm (Heidegger 1962: 79). The Being-in is not contained but rather exists ‘‘alongside’ the world in the sense of being absorbed in the world’ (Heidegger 1962: 80-81). Likewise for Merleau-Ponty, '[t]o be a body, is to be tied to a certain world, as we have seen; our body is not primarily *in* space: it is of it’ (2002: 171).

Having established Being’s in-the-worldness—its position within Welt—the actual meaning of Being must be clarified. ‘[T]he Being of Dasein itself is to be made visible as *care*’ (Heidegger 1962: 83-84), that is, ‘concern and solicitude’ for other entities (1962: 237-241). Being is the vessel, corporeal or otherwise, for emotions and attitudes. Being is also the agent/actor, whereas Dasein is the seat of agency that is ultimately embodied in Being. Dasein is only capable of enacting agency through Being-in. The relationship between Being and Dasein is not one of convenience;

> *'Dasein is never 'proximally' an entity which is, so to speak, free from Being-in, but which sometimes has the inclination to take up a 'relationship' towards the world' (Heidegger 1962: 84).*

Fundamentally, Dasein can never exist independent of Being.

There are a variety of methods for defining, investigating, and exploring space ranging from traditional visual examination of site plans through to access theory. Yet it is the use of the body (real or envisioned) as an analytical tool, which observed to be the most appropriate method for elucidating past use of space.

> *'By considering the body in movement, we can see better how it inhabits space (and, moreover, time) because movement is not limited to submitting passively to space and time' (Merleau-Ponty 2002: 117)*

Lefebvre (1991: 170) empowers the body and says that is capable of creating space. This space is in the Heideggerian sense of *Umwelts*, and as actions and behaviours are routinely practiced within locales, the body is able to inscribe places. Whilst the body is seen to create space through the construction of architecture, this is not to suggest that tangible material outcomes need be visible for the body to have defined space. For Lefebvre it is the corporeal form that is most potent in the world, 'living body is space and has its space: it produces itself in space and it also produces that space' (1991: 170). However we must not take Lefebvre's conception of the body in space at face value. For Heidegger, Being-in is in *Welt* through the act of inhabitation, but does not have its own space—rather, Being-in has presence. Further, for Merleau-Ponty '[a]nd finally, far from my body's being for me no more than a fragment of space, there would be no space at all for me if I had no body' (2002: 117). *Welt* is the arena which affords the intentions and actions of individuals. Furthermore it is only through those actions that Beings are capable of creating and crafting *Umwelt(s)* within *Welt*.

All movement and activity undertaken by humans in the environment is both constrained and facilitated by the body, as it acts 'as a conduit linking the physical sensations of technological activity with human corporeality and sentience, and by extension, with awareness and understanding of the physical self and the world more generally' (Dobres 2000: 75). In essence, Being mediates the recursive interaction between Dasein and *Umwelt*, through its presence in *Welt*. Our realisation of this dialectic facilitates using the human body as an analytical tool to interrogate space, thus we can reveal aspects of practice and potentially agency whilst appraising the pragmatics of such actions (*cf.* Audouze 1987).

AGENCY, AGENTS, ACTION, AND ACTORS

To acknowledge skilled individuals with a capacity to act as agents demands that we clarify what is meant by agency. All individuals essentially are capable of agency, but not all actions are the product of those individuals' agency. Actors and agents can be one and the same, but are not inherently so. The actor is the vehicle through which agency is enacted and can be an entirely distinct individual from the agent. Agency is not synonymous with action. Agency is itself made manifest through action, however all action is not necessarily the result of agency. Agency refers to an individual's ability to act and focuses on an individual's capability and choice, *e.g.*, Giddens who understands agency simply as the power to act (1984). Whilst this definition of agency is in part true, its simplicity serves to mask the much more expansive underpinnings of the concept.

Problems with Space and Agency

A number of scholars, notably Giddens, Barrett, and Dobres, have all attempted to develop an theory of agency in relation to their own studies and in doing so have had to tackle issues of space, agency, and practice. While it is clear that there is great potential in such approaches for the way practice is rooted in space, none of the proposals to date are complete or without issues.

Whilst there remains no consensus as to the meaning of agency (Dobres and Robb 2000b), it is useful to construct a viable definition so as to guide our understanding of what current studies achieve in connecting with this concept. Agency cannot be equated to practice, nor can it be reduced to individual action (Barrett 1994b: 5). Rather, agency concerns the potential of action in a particular context and, as such, agency must always be located in *time* and *space* (*i.e.*, in *Welt*). Being located in the world, agency also draws on material resources, it is *materially* contingent. Likewise, agency is always knowledgeable, even though that knowledge is often partial, incomplete and ever changing; as such it is *historically* situated and it is through agency that the past is brought to bear on the present. This definition of agency is borrowed in most part from the works of Barrett (1988, 2000, 2001), with the origins of this model of agency lying firmly in the writings of Heidegger (1962). For Heidegger, materials are in-the-world, they inhabit *Welt*, both ready-to-hand, as *equipment*, and present-to-hand, as *materials*

(1962: 190). Dasein's knowledge and memory, aid in making the distinction between the two states, *i.e.*, in identifying equipment. Tradition or memory inform Dasein, providing perspective and background that situates Dasein and ultimately specifies the roles of equipment.

In discussing the bases of social activity, rather than simply the arenas of its enactment, Giddens established the foundations for a distinguishable framework of agency:

> *'[s]ocial activity is always constituted in three intersecting moments of difference: temporally, paradigmatically (invoking structure which is present only in its instantiation) and spatially. All social practices are situated activities in each of these senses' (1979: 54).*

This concept of paradigmatic situatedness is at the heart of his theory of structuration. The notion that social structures do not determine behaviour and actions, as structuralists (Sahlins and Service 1960, Lévi-Strauss 1963) have long championed, but rather influence and afford the actions of people in the guise of tradition was a radical way of reconciling how individuals serve to create and recreate the world they inhabit.

What is lacking, however, from Giddens' theory of structuration, as it applies to agency, is intriguingly the material aspect (1984). Whilst he presents a nuanced discussion of the underpinnings of action in society, his conception of agency remains oddly immaterial. At the societal level Giddens' ideas are revolutionary and present a workable rejection of structuralism that accounts for both continuity and change in the world. Yet, without the material component, it is often unclear how Giddens' actors manifest their agency. For Giddens the material component is either subsumed within the paradigmatic structures as a key aspect of tradition, or it is an immovable part of the physical world; never does Giddens see materials as the dynamic resources that they are. His model of social action does not empower materials in terms of agency. Giddens never shows how individuals act through materials to manifest agency. When Giddens finally turns his attention to material constraint, he defines it as such: '[c]onstraint deriving from the character of the material world and from the physical qualities of the body' (1984: 176). This definition curiously presents these constraints as an apparently dichotomous anomaly: on one hand the material world serves as a resource akin to space, and simultaneously as a force that reacts against actors to prevent the realisation of their agency in *Welt*. At the level of the individual, the agent, the actor, Giddens never resolves how his material constraints affect the manifestation of agency, and his premises are often lacking in depth. In *Central Problems* he remarks

> *''Action' or agency, as I use it, thus does not refer to a series of discrete acts combined together, but to a continuous flow of conduct. We may define action, if I may borrow a formulation from a previous work, as involving a 'stream of actual or contemplated causal interventions of corporeal beings in the ongoing process of events-in-the-world'' (Giddens 1979: 55).*

Though Giddens' idea of action as explicated is not entirely atypical, his conflation of action with agency is problematic. Action is the translation of agency into practice; they are not synonymous. His conception of action, thereby seemingly does not allow for any action that is unintentional or so habituated that it is essentially reflex action. Furthermore, Giddens is overly concerned with the result of actions, rather than the actions themselves as they feed back into the recursive cycle. Actions are dismissed as the vehicle of structuration rather than a key component in and of themselves. The importance of action is taken as self-evident, but is unfortunately passed over in terms of dissecting the impetus underlying those actions. Giddens believes in differing states of consciousness, yet he does not consider the resultant divergent states of action, performed in those states. Nor does Giddens adequately resolve the distinction between agent and actor, perhaps not even acknowledging one (1984: 51).

In the opening to *The Constitution of Society*, Giddens makes a somewhat Heideggerian declaration that

> *'To be a human being is to be a purposive agent, who both has reasons for his or her activities and is able, if asked, to elaborate discursively upon those reasons' (Giddens 1984: 3).*

Thus for Giddens, to be in-the-world, one must be an agent at all times, in some respects permanently fusing Being and Dasein into a singular whole. Moreover, Giddens is focused on the body as the vehicle of action, rather than the mind as the seat of agency. 'Concern with the body, as locus of the acting self and as positioned in time-space, is the key linking theme of the material discussed and analysed' (Giddens 1984: 41). The preoccupation with the corporeal self runs directly counter to Heidegger, Merleau-Ponty, Lefebvre and others who view the body as the vehicle of action yet not the locus of agency.

Beginning in the 1980s, Barrett's writings on agency have been simultaneously persuasive and provocative. The opening premise of his article *Fields of Discourse* bravely posited that the archaeological record simply does not exist and instead we are witnessing evidence for 'particular social practices' (Barrett 1988: 7). It is the recognition and understanding of these social practices that has come to dominate Barrett's work from the 80s until the present day (Barrett 1988, 1989b, 1989a, 1994b, 1994a, 1997, 2000, 2001). Initially strongly influenced by the work of Giddens and his concept of structuration, Barrett readily adopted Giddens' idea that all action occurs within time/space and is carried out by knowledgeable agents (Giddens 1984). However, as Barrett adopted Giddens' ideas he also adapted them to incorporate the missing component of the material world. Yet at this stage in his writings, the material world as conceived of by Barrett is an intriguing fusion of *Welt* and historical constraints, explained as the concretised cultural resources and structural conditions that serve to influence agency are perhaps best understood as *tradition*. Though this *Welt* is ostensibly the locus of, as well as the conditions for, agency, it still fails to explicitly provide the necessary material constituents of agency.

In *Fields of Discourse*, Barrett is largely critical of the poor application of theory in present research and notes that in 'current archaeological thinking time and space are merely employed at a descriptive level' (1988: 10) that is ignorant of the potential of concepts such as time/space (*Welt*) for elucidating past practices. In expanding upon this premise, Barrett introduces his concept of *fields* which represent 'an area in time-space occupied by virtue of the practice of a particular discourse' (1988: 11). The idea of the *field* is largely comparable to that of *Umwelt* based upon Heideggerian notions of time/space. However, the premise that fields are only occupied or inhabited through practice is also evocative of Ingold's later concept of *taskscape* (1993, 2000). Following on from that article, Barrett developed further the idea of material conditions in relation to agency, '[m]aterial culture represents the material universe which was partially available for humans to draw upon as medium for action' (1989a: 305). This statement is illustrative of Barrett's acknowledgement of the recursive nature of materials and material culture in practice, and further, their inextricable role in agency.

In the 1990s, in *Fragments from Antiquity*, Barrett reiterates that tradition is a necessary condition of agency, allowing for the production and reproduction of structural conditions (1994b: 36). Further, this translation of tradition into practice is mediated through material culture, again producing and reproducing itself as conveyed in his earlier writings. Whilst Barrett had spent over a decade, at this time, writing on agency, he has ultimately evaded codifying his definition of agency. It was not until the next decade that Barrett presented a comprehensive treatise on his ideas on the concept of agency (2000). Though this work presents his most developed theory of agency, Barrett is wise to caution that we must not reify the concept. Just like the agents we speak of, the notion of agency itself must be situated in-the-world. In this way we are made all the more cognisant of the logical fallacy of divorcing action from context in *any* discussion of agency. The importance of contextualisation is particularly relevant to the present work, chiefly his proposition that

> *'analysis cannot be dedicated to the representation of agency as the object of our inquiry; rather it must work on the time/space field of resources through which agency constitutes itself in its actions' (Barrett 2000: 63).*

Additionally, agency and agents cannot be divorced from other beings-in-the-world, as 'agency cannot be analysed in terms of isolated beings', echoing what was evident from Heidegger's portrayal of Dasein as ultimately relational and thus inherently social (Barrett 2000: 61, Heidegger 1962).

Our analytical capabilities will always be limited to material residues, yet if as Barrett (2000: 64) theorises those residues are the consequence of agency's actions and not agency itself, we must remain cognisant that we are often excavating the residues of unintended consequences. Barrett remarks, 'the material conditions which are investigated archaeologically are the contexts in which an agency was once able to construct itself' (2000: 66). Such a careful investigation of the material contexts (not in the archaeological excavation sense, but rather the *Umwelt* that comprise such contexts) of the material residues of agency's actions can then ultimately reveal something of agency itself.

Barrett's *Thesis on Agency* closed with a call to arms, a plea for the adoption of an archaeology of inhabitation 'fundamentally concerned with the situated context of action' (2000: 67). This archaeology is inherently concerned with agency rather than action, the social milieu rather than the individual, and challenges us to contextualise practice via the medium of material residues. Expanding upon this premise in the following year, Barrett importantly recognises the dual notions: 'Practice necessarily requires the presence of an agent' and 'Agency is always situated in structural conditions which facilitate its actions because agency requires a medium through which to work' (2001: 149). Thus both Beings-in-the-world, as well as equipment that is ready-to-hand for Dasein, represent the media through which agency is enacted in *Welt*. Ultimately, these embodied agents are reliant upon the material world in order to make agency manifest through practice (Barrett 2001: 149-150). These dual media of the agent and the material world are critical to the translation of tradition (or knowledge) through agency into practice; yet, agency is not the product of these elements alone. Barrett is cognisant that whilst these Beings are knowledgeable and well-equipped, without context they are incapable of being agents. When ‘we lose sight of the situated nature of practice over time and space’, we fail to embrace all the aspects responsible for agency (Barrett 2001: 157). Here at last in this article we find Barrett laying out plainly, the necessary components of agency: knowledge, material structural conditions, and fields (2001: 157-158). *Knowledge* is the concretisation of past practice—tradition and memory stored individually as well as collectively. *Material structural conditions* are both the medium of agency’s actions as well as the product of those actions, and *fields*, (*i.e.*, *Umwelt*), represent the arenas in which agency can be enacted—the realms where practice is played out.

Social agency, the term that Dobres is most fond of utilising throughout her writings (Dobres and Hoffman 1994, 1999, Dobres 1995, 2000), is somewhat redundant. As witnessed above, all agency, by its very nature, is unavoidably social. Agents cannot act without relation to one another, either through their knowledge of the past or via their interactions in the present. As agency is informed by knowledge, tradition, memory—the structural conditions that are at the heart of society are always brought to bear upon practice. It is practice that in turn serves to (re)construct those structural conditions to recursively create society (Giddens 1984). Dobres often places too much import on separating human agency from social agency and falsely views human agency as the key to revealing the individual in the past. For her the notion of embodied practice is an important concept that needs to be embraced to fully understand how agency is enacted in *Welt*, albeit strictly through the lens of the individual. Dobres’ (2000: 5) statement that ‘[t]his socialized, constructed, corporeal, and mindful body is nothing less than the essence of technological practice' is a clumsy attempt at reiterating the Being/Dasein relationship, that of the *semi-corporeal* Being and the *incorporeal* Dasein, that yet again misses the point. By privileging the body over the being, she is highlighting her preference for studies that focus on the individual. It is much easier to discuss individuals and identities when you are defining agents by the bodies that they occupy. Dobres seemingly focuses on the corporeal agent to emphasise her dichotomy between human and social agency, neglecting the truth that all agency and therefore agents are social. However this dichotomy is itself a fallacy, as Being cannot be contained in the world as a body but rather inhabits it. The term ‘body’ seems to unfortunately capture Being/Dasein and contain it in a manner that is not possible. Being cannot be defined or delineated by its corporeality alone. But Dobres is at pains to emphasise the extra-corporeality of agency. The notion of Being’s semi-corporeality brings to mind ideas from Giddens of presencing at a distance. Being/Dasein extends its supposed corporeality through the enactment of its agency. Being, by virtue of being-in-the-world, is never simply corporeal. Being cannot be contained by *Welt* and is not bound by corporeality; rather Being inhabits or dwells in the *Umwelt(s)* that its own actions, rooted in Dasein's agency, cause to come into being within *Welt*.

Notwithstanding being the author and editor of two volumes explicitly on agency, as well as many other articles, Dobres (2000, Dobres and Robb 2000a) surprisingly seems not to present a coherent concept of agency. In the introductory chapter to *Agency in Archaeology*, she in fact gives two differing definitions of agency that she has used:

> *'A process of intersubjective engagement with the material and social world', or*
>
> *'The successful deployment of discursive and non-discursive technological knowledge and skill' (Dobres and Robb 2000b: 9).*

Neither definition is particularly illuminating and instead she typically defaults to a discussion of the role of agents in a recursive relationship with structures *cum* Giddens' structuration as well as favouring discussions of 'social agency', which might be better understood as Giddens' (1984) *structural principles*. Further, though Dobres is comfortable referring to the work of Barrett and his treatment of agency, she never fully embraces his elucidation of the concept. For Dobres, agency is at its essence a social phenomenon, albeit carried out by individual agents. Moreover, Dobres faults philosophical discussions of technology for their lack of 'concrete, context-specific, material grounding' (2000: 88), yet her own discussions are equally lacking. Dobres has rightly emphasised the active role of materials in discussions of agency, however she has largely decontextualised them. She emphasises how she is cognisant of the individual agent as well as the social milieu in which s/he exists, yet leaves her agents worryingly un-situated in space. The only grounding they have is as producers within a complex social web.

Dobres is conspicuously influenced by the works of Marx and Foucault and her writings are coloured by a preoccupation with political structures and the notion of power. This concern for politics is evident in her preface to her discussion of Heidegger. Dobres (2000: 80-84) is seemingly influenced by *Being and Time*, yet her treatment of Heidegger's works glosses over much of the more nuanced aspects of the non-dichotomous relationship between Being and Dasein. Moreover her unsurprising focus on technology and his *The Question Concerning Technology* (Heidegger 1977) in particular, serves only to ignore the more fundamental ideas Heidegger presents on the nature of action itself. Her concern with technology as a reified social entity prevents her from understanding the underpinnings of technology and technologies, as explicated by Heidegger, at the most basic level of *individual* agency and action. Dobres needs to reject systematist views of the past that see technology, politics, economics, *etc.* as differing spheres of action and influence. If the vast majority of past action is reducible to agency then that is the lens through which we must hope to understand the past.

It is difficult to reconcile Dobres' usage of agency, practice, and *habitus* theory throughout her treatise of *social agency*. At times Dobres (2000: 131) rather flippantly refers to the 'patterned material behaviors of unconscious agents obliviously (but faithfully) going through the motions'. It should be argued that intentionality is a key component in agency, there are without doubt always unintended consequences to actions, but the impetus behind them had a core of purpose. The 'unconscious agents' that Dobres speaks of are oxymoronic. Agency requires consciousness, action does not. If we are to replace agents with 'actors' then her premise can be considered, however it still exhibited a confused conception of agency which dominates Dobres' work.

CHAÎNE OPÉRATOIRE

The c*haîne opératoire* devised by Leroi-Gourhan, a student of Mauss, was a proposal based on the observation that technological practice offered a means to investigate a society through the manner in which they organised and critically performed craft through its various steps (Leroi-Gourhan 1943, 1945). The approach recognised that the organisation of production was culturally specific, not just in terms of material choices but also the performance of the technology itself, that is the bodily deportment of craft workers as this is how technique was enacted. Subsequent employment of the *chaîne opératoire* in archaeological and anthropological studies focused its use towards the methodological description of operational stages (especially in the study of lithics) with the organisation of specific steps being held to indicate particular cultural choices (Dobres 1999, Edmonds 1990a, Schlanger 1994, Shott 2003, Lemonnier 1976).

The performative aspect of the *chaîne opératoire* coupled with its emphasis on cultural selection of materials allowed the full introduction of the human agent back into the study of ancient technology, in stark contrast with material culture studies, especially in metallurgy, which had become mired in laboratory analyses and the definition of technical process where social action and choice has been forgotten (Goodway 1991). *Chaîne opératoire* was one of the first attempts to animate objects, to endow them with life histories that could be uncovered (Dobres 1999). Dobres, for instance, is happiest envisaging the *chaîne opératoire* as a dance or performance put on by the skilled practitioner under the guise of technical production, whilst many others reduce the *chaîne opératoire* to a production sequence or fabrication pathway involving little more than selection of technique and material (*e.g.*, Shott 2003).

Schlanger (1994: 143) too, is hopeful that

> *'If the becoming of material culture and the succession of material actions can be reconstructed on the basis of static archaeological remains, then the active mind of the past may well be, after all, within reach'.*

For Schlanger, *chaîne opératoire* is the tool of choice for excavating the ancient mind. However, his conception of the 'technical act' presents a definition of agency lying somewhere between structuralism and structuration:

> *'It is the case that the technical act, dealing as it does with physical entities, is bound by material constraints and regulated by universal propensities and natural laws' (Schlanger 1994: 144).*

The material constraints of Schlanger are certainly recognisable (unlike with Giddens) and his universal propensities can be interpreted as structure, tradition, and memory with natural laws representing actual physical limitations within the world. Nevertheless, for Schlanger, these technical acts are still unsituated, as they seem to be for many others who discuss ancient technique.

In contrast, Dobres is often too focused on the skilled body, choosing to emphasise the performative element of the *chaîne opératoire*, and neglects to reconcile the individual with society. Though the stance that Dobres (2000) takes on technology, largely influenced by the work of Pfaffenberger (1988, 1992, 1999), is bold, it is somewhat superfluous when taking an agency-centred approach to the past. There is no need to explicitly emphasise technology as a social phenomenon when we clearly must view all actions and the material world, created and recreated through those actions, as social. Dobres convincingly argues for sociality of technology and does so by emphasising the *chaîne opératoire* and the performative aspects of technology (Dobres and Hoffman 1994, Dobres 1995, 1999, 2000). The problem, however, is that this conception of technology appears to locate the social aspect of technology in the *performance* alone. It is as if the social dimension of technology is only realised through the conscious witnessing of the technical act. The skilled performer, the knowledgeable agent is social, but for Dobres their sociality only comes into the world through skilled practice. What Dobres disregards is that the totality of technology is social, as is emphasised repeatedly by Pfaffenberger (1992, 1999); and we cannot partition the technical from the social in the productive process. We must reconcile potentially competing concepts of performance and practice. All performance and practice is negotiated in and with-the-world with a guaranteed audience comprised of all Beings and *Welt* irrespective of presence. Performative action, nor practice, requires a conscious audience.

Dobres' treatment of *chaîne opératoire*, though often some of her most convincing work, still leaves inviting avenues for exploration. One such argument hinges on the ability to detect 'normative procedures' in the archaeological record, enquiring

> *'how widely shared was some sequential strategy for the production, use, and repair of different classes of artifacts? How much variability was "tolerated," favored, or discouraged?' (Dobres 2000: 179).*

Her ideas here hinge on observable differences in artefacts and have seemingly very little to do with the actual recognition of artifice (*i.e.*, Dobres' own conception of agency enacted). It is a truth universally acknowledged that differing practices can produce similar products. Yet, whilst Dobres might be adept at identifying normative products, she does little to explicate how this insight extends to the determination of normative practices. More broadly, this (ignored) distinction between practice and product calls into question just how Dobres recognises the *chaîne opératoire* archaeologically and ultimately reconciles the distinction between agency and *habitus*.

Dobres is rightfully attracted by the idea of detecting identity in the *chaîne opératoire*, largely through variations noted 'how and when technicians strayed from their procedural "center,"' (2000: 181). She endeavours to extend these discussions of observed variations from normative practices, to attempts at identification of hands and thus the individual and his/her identity. However, Dobres' discussion of *chaîne opératoire*, for all her statements to the contrary, largely treats the concept as a technical recipe of sort, presenting a scenario in which craft practice is rule bound—a position that blatantly reads as an endorsement of structuralism. Also rather than discussing variation as a natural occurrence in craft practice, Dobres (2000: 205) declares these observable differences as evidence of *deviation*, denying the real agency of the craft producers that is inherent in Giddens' (1984) conception of recursive change and innovation through practice. The more Dobres argues for agency, the weaker her arguments become and ultimately she (inexplicably) strips her agents of free-will:

> *'The individual body is, however, socialized to its very core; and just as one never has a direct and existential experience with things-in-themselves to which they "apply" meaning, there is also no such thing as a free-willed, self-referential agent*

> *able to divorce themselves from or exist outside, the sociopolitical structures and symbolic constructs in which they exist' (2000: 215-216),*

embedding them in a structuralist environment, that though fully social, is bereft of the potential for truly individual action. She fails to see the distinction between action that is based upon agency and free-will, and the structuring principles that have influenced that action. Though the *chaîne opératoire* approach has adroitly examined the processes by which artefacts are constructed, its day to day use has concentrated on technical and material choice at the expense contextual and performative choice not recognising the role of time and space in production.

CRAFTING-IN-THE-WORLD

Crafting *Umwelt*

Lefebvre's *Production of Space* (1991) serves as a crucial resource in the examination of agency, crafting, and the world. The discussion heretofore has struggled with differing terminology, often only distinguished by the most nuanced of connotations. Lefebvre wisely reminds us that

> *'the term used is far less important than the distance that separates 'ideal' space, which has to do with mental (logico-mathematical) categories, from 'real' space, which is the space of social practice. In actuality each of these two kinds of space involves, underpins and presupposes the other' (1991: 14).*

Regardless of terminology—and when it comes to discussion of space and the world we must accept that there is no *lingua franca*—we can agree that our actions in the social realms create and recreate an arena of practice. The 'social spaces' of Lefebvre are most akin to the *fields* of Barrett (1988) and our Heideggerian derived *Umwelts*. Lefebvre's (1991: 86) observation that '[*s*]*ocial spaces interpenetrate one another and/or superimpose themselves upon one another*' acknowledges how *Umwelts* are created within *Welt* and each other, much like how the recursive structuring principles and institutions of Giddens (1984) ceaselessly build upon each other both spatially and temporally from the *durée* to the *longue durée*. For Lefebvre, '[s]ocial space *per se* is at once *work* and *product* - a materialization of 'social being' (1991: 101-102), perfectly encapsulating the notion of the recursive link between *Welt*, agency, and *Umwelt*. Agency is situated within *Welt*, through the *Umwelts* that are crafted through practice, these *Umwelts* themselves have a history and aid in the further constitution of agency through their material components. By crafting objects, we are also simultaneously crafting the world and living in the world. Craft is in fact agency enacted. Crafting is a practice of continual unfolding, of becoming, not only of material culture, but a process by which one creates and recreates *Umwelts*, which ultimately endure as a physical remainder of past practices.

Why Craft?

Whilst craft has most often been studied through careful analysis of artefacts, as the introduction stated, craft is not reducible to objects alone. The last two decades have seen the proliferation of 'technology' studies which acknowledge a) the social embeddedness of technology; b) the role of choice in production; and c) the centrality of the 'body' in understanding the development and transmission of craft traditions.

However, too often the products, as well as the processes, of craft have loomed un-tethered to practice, remaining un-situated in *Welt*. Craft can be considered to be the physical manifestation, the realisation, of agency through performance or practice. If we can confidently acknowledge that craft is agency put into practice, then is it not self-evident that 'technology concerns the active involvement of social actors in the day-to-day creation of their material world' (Dobres 1995: 27). Discussions of technology as a fully social practice are beneficial yet ultimately miss the point in not making the direct connexion between the actions inherent in any technology and the more primal concept of agency. Dobres treats technology as 'an arena in which different kinds of interests can be defined, expressed and negotiated' (1995: 27). Yet, technology is not the arena, but rather the marriage of practice and medium, the enactment of agency made manifest to us through its material products. Further, arguments concerning the relationship between technology and society are admirable yet simply unnecessary as technology or technological behaviour is agency made manifest through practice and thus *is* social. Technology is the material world (re)constructed by agency. It is knowledge and matter situated in *Welt*. It is fundamentally how agency becomes in-the-world.

Technology of Craft

At times it seems that we should abandon altogether the usage of technology for describing the activities and outcomes that are collectively considered craft. Technology, for all its modern connotations, though at times an accurate representation of craft, carries with it copious ontological baggage. Craft is the careful manipulation of the material world through the actions of knowledgeable and historically informed (and contextualised) agents situated in *Welt*.

From the outset, the study of craft has excelled at highlighting the time aspect of agency at many levels from the carefully constructed chronologies and typologies to the individual production regimes, *e.g.*, firing, of individual artefacts. These catalogues of artefacts have enshrined the object as the primary focus of study. Only within the past few decades have scholars sought to expand their inquiries in craft to include other dimensions of agency. Through anthropologically influenced perspectives, studies have looked to the material constituents of production as well as the traditions of practice most clearly understood as techniques. These newer studies often invoke the name of agency yet remain incomplete at they too often avoid any discussion of space. Objects have the potential to reveal a great deal about the agents that produced them (*e.g.*, Uomini 2009), yet in themselves they struggle to reveal space. Without contexts of production there can be no meaningful study of agency. To reiterate our Heideggerian (1962, 1977) stance in approaching the study of craft from an agency perspective we must look at craft producers as Beings-in-the-world, fully situated within the spatial as well as temporal dimension.

Practice makes Craft

Craft practices create the fabric of the world whilst weaving together diverse threads of social life. Practitioners must continually consider both the physical limitations of their materials as well as the social expectations which frame their craft. In this way, crafting is both produced by and produces a society through the manipulation of the material world.

Perhaps owing much to the antiquarian origins of archaeology, the study of crafts and craft production has tended to focus on *objet d'arts*, the treasures from the past that delighted the collectors of the seventeenth and eighteenth centuries. *Things* have held archaeologists in their thrall for centuries as objects have helped to outline chronologies through carefully crafted typologies (Gerloff 1986, Peacock 1969). They have also defined cultures through the regular occurrence of particular assemblages (Griffiths 1958, Childe 1929). More recent attempts to anthropomorphise artefacts, most notably in the new stream of scholarship into object agency (*e.g.*, Gosden 2005, Knappett and Malafouris 2008a, 2008b), have naïvely missed the mark. Knappett and Malafouris argue in their introduction to the concept of nonhuman agency, that the defining characteristics of agency are stacked against material agency, 'When agency is linked strictly to consciousness and intentionality, we have very little scope for extending its reach beyond the human' (2008b: ix). In some respects they have only served to set up a straw-man, in using this rather weak conception of agency that is ultimately rooted solely in the mind of the individual rather than the social *milieu*. Malafouris' more nuanced model of *material engagement* is certainly more palatable (2008). His model admits things lack agency, but it also privileges materials as the media through which (human) agency is enacted. Even if agency must unavoidably be enacted through materials, that action comes into being in human consciousness, *not* in things themselves. Individuals possess consciousness, but things—only have thing-ness, the distillation of their existence—not essence *cum* Dasein—in the world. What has been termed material or object agency can perhaps be best understood from a cognitive perspective as reflex action as well as materiality. These things do not have agency, yet they do influence or afford certain behaviours in the agents that utilise them (Pfaffenberger 1992: 503, Miller 1983). To endow them with the puissance of agency is to strip away the complex underpinnings of the concept and to reduce it simply to instinctual action.

Craft production is a social process that must be situated to be understood. These objects may influence or even encourage certain behaviours and practices but to bestow the mantle of agency upon them is to exhibit the grossest ignorance of what agency actually is. In a sense we are primed to perceive these objects as permitting or promoting certain behaviours, which is not the same as these objects actually exhibiting the potency to initiate action (*cf.* Merleau-Ponty 2002). We can concede that objects have power, not the power to act, but the power to influence action. Objects can only manifest their potency though a human agent.

SUMMARY

If archaeology is the study of past peoples and their actions and material culture then it needs be a study of agency. Our analysis of past practice must acknowledge that we do not occupy an *a priori* world but rather inhabit the continually constructed and (re)constructed residues of agency. These residues however are not necessarily the product of agents directly; for not all individuals are agents and it is therefore naïve to utilise the study of agency as a proxy for uncovering the individual or identity. The notion that one cannot reasonably excavate the individual makes it seem almost impracticable to reveal agency. However, having maintained that objects are incapable of agency does not preclude objects from revealing agency itself. In the same way that

Ingold (2000) sees artefacts as the crystallisation of routine bodily practices, architecture can be seen to be the result of such routinised behaviour, but critically, such architecture also structures how the body is used (Parker Pearson and Richards 1994b, 1994c, Barrett 1994a). And only through an analysis of space that utilises the body as the primary unit of measure can we begin to reveal how space was inhabited in the past. This idea is central to the concepts of *habitus* for Bourdieu (1977) and *structuration* for Giddens (1984), and is manifested in the creation of *Umwelts* and their subsequent use. What is required is a study of situated action, enmeshed and inseparable from the social and situational milieu of the past. For as has been illustrated agency is inseparable from time and space and its material residues must be considered in a relational manner. Our emphasis must be the acts and arenas of production and the reunification of products with their formative processes.

Chapter 4. Occupying the Iron Age

INTRODUCTION

Recent studies of the Iron Age have drawn attention to this period being characterised by a preoccupation with space in all its forms (Fitzpatrick 1994, Fitzpatrick *et al.* 1995, Hingley 1990a, 2006, Giles and Parker Pearson 1999, Bowden and McOmish 1987, 1989, Parker Pearson 1999, Parker Pearson and Richards 1994c, Parker Pearson *et al.* 1996, Boast and Evans 1986, Hill 1994a, 1994b, 1996). It has been argued that Iron Age communities appear to have continually structured space, and practices through the ongoing reworking of materials, space, and practice. The pervasive nature of this investment in space makes it a potentially useful perspective through which to examine the technology of production. There has been considerable debate as to whether this is a novel phenomenon for the Iron Age, or merely a continuation of much older practices. Bradley (2012), in his most recent work points to an overarching *idea of order* that societies, in Britain and across the globe, favoured circular structures, over rectilinear ones, at varying points in time. Though Bradley rightfully recognises a preponderance of circles in prehistory, and the more recent past, he appears to overstep in conflating all circular forms irrespective of medium. He has no difficulty considering the hemispherical mounds of passage tombs, penannular ring ditches, roundhouses, and even circular motifs on pottery, as representative of a global cosmos. Whilst all of these forms share a similar shape, the manners in which they are constructed and used are quite different. It is unclear if Iron Age people were any different to their predecessors or rather, that we recognise patterns archaeologically, in their domestic architecture, in a way that has been less apparent to us for other periods. However, in the first millennium BC, the novelty is not that of building round structures, but instead dwelling within them. In many respects it is that act of enclosing oneself within the structure, either the roundhouse or the ringwork or the hillfort that is significant.

Any understanding of space needs to acknowledge the wide-ranging conceptualisations and analyses of space that have assembled around studies to establish ‘space’ as such a significant intellectual commodity. This diversity of methods is exemplified by the two contrasting approaches of Parker Pearson and Richards (1994a), who view space as socially created and constrained, and Hodder and Orton (1976), whose processual approach considers space more as backdrop to the patterning of settlements and artefacts. Interestingly, it is the work of Ingold (2000) that has influenced much of the current discourse on space, though it is notable that he outright rejects the term 'space' and instead uses landscape, which he 'defines' as being *not* land, *nor* nature, *nor* space.

The last two decades have seen a developing interest amongst Iron Age scholars as to how space was both occupied and utilised as such a commodity during later prehistory. Oswald's study was amongst the earliest (1991) and drew attention to the orientation of entrances and the predominance of south-eastern facing entrances. This realisation was further developed by Fitzpatrick (1994, Fitzpatrick *et al.* 1995), and later Parker Pearson (1996, 1999), who saw this orientation preference relating to the distribution of light, and in turn specific activities within Iron Age structures. At the same time as architectural form and orientation of roundhouses were viewed as significant, the use of space, and specifically the location of specific practices, was also seen as meaningful (Chadwick Hawkes 1994, Fitzpatrick *et al.* 1995).

There are now a plethora of studies that advocate ways in which space gathered meaning within Iron Age studies (*cf.* Giles and Parker Pearson 1999, Barrett 1999, Bowden and McOmish 1987). Many have approached this from either a loosely structuralist perspective or a more nuanced agent-centred approach at varying scales, whilst some have tailored methodological approaches to better address these problems (Parker Pearson *et al.* 2004: 71-74, Barrett 1988, 1994a, Doonan *et al.* 2001, Doonan and Mazarakis Ainan 2007, Giles and Parker Pearson 1999). Despite the number of papers which have emphasised the use of Iron Age space, few have considered space at the scale between the site and the roundhouse, that is, those spaces within the site in which practice played out. It is argued here, following Ingold (2000: 192), that '[a] place owes its character to the experiences it affords to those who spend time there'. The features that populated the Iron Age world were not static backdrops for the whole host of human activity. These structures, from linear boundaries to the interior divisions of wheelhouses were largely prescriptive in nature. However, to use Ingold's line of reasoning, the emphasis should not be placed on what structures allowed (and at the same time, what they constrained), but rather what they afforded. Arguably then, there is a need to move from perspectives that too often class less significant features in a way that renders them virtually impotent, to a perspective that instead emphasises the potential of features and associated spaces to accommodate the routines of social life.

The attention to space that scholars of the British Iron Age have developed is something mimicked in kind, but not intensity, within scholarship of other periods, to the point where much of the theoretical literature relating to the use of space is often illustrated by Iron Age examples (*cf.* Hodder and Orton 1976, Parker Pearson and Richards 1994a). Building practices in the Iron Age have been characterised as 'obsessive', 'excessive', and 'constraining' (Bowden and McOmish 1987, Guilbert 1975, Hill 1996), and have been held to reveal a new found interest in how space can be utilised. Houses and enclosures were no longer simple constructions (Hingley 1990a), but rather provided the context for all activities, and as such organised the way in which individuals engaged with and reproduced their worlds—both the material and ideological. Chadwick Hawkes was amongst the first to highlight the organisation of space within roundhouses in her work at Longbridge Deverill Cow Down. As early as the sixties, Chadwick Hawkes had noted the seemingly ordered distribution of specific artefact types with the roundhouse (1994). The idea that Iron Age spaces might be ordered was evidenced on a much grander scale by Guilbert (1975), who remarked upon the 'almost obsessive desire' of the builders of Moel y Gaer to orientate their houses eastwards. Giles and Parker Pearson later elegantly summarise the role of the roundhouse in the Iron Age

> *'the timing and spacing of activities within the dwelling was drawn from an understanding generated through the wider temporality of work and that the wheelhouse, and the roundhouse, may be posited as an embodiment and an organising artefact of the annual as well as the diurnal cycle of Iron Age life' (1999: 225).*

Whilst the possibility of generic domestic activities being spatially and symbolically structured is readily acknowledged, less attention has been paid to how specific craft endeavours such as metal production, were organised in space, be that within the roundhouse, or articulated within a wider landscape (Ehrenreich 1985, Doonan *et al.* 2001). There is still a paucity of studies that address the spatial articulation of craft activities, likely due to manifold reasons, which might include a prolonged alienation of technology from mainstream social anthropology and archaeology, and a reticence by archaeologists to engage with particular classes of material (*i.e.*, slag). There seems to be a broad acknowledgement of the structured deposition of materials (Hill 1995, Hingley 1990b), yet these studies have tended to acknowledge only the 'ritual' practices rather than the routine. Craft is one such routine practice that could benefit from a theoretically informed approach that acknowledges structured deposition in the residues of its practice. Necessitating an appreciation of the notion that it is through the residues of those practices, such as craft, that space was constructed, structured, and reproduced, and in turn allowed specific symbolic meanings to accrete to place.

Space has then been commoditised as a useful intellectual resource within Iron Age studies, yet in its categorisation, be that functional or symbolic, it has stimulated a concomitant interest in what delimits one space from another, *i.e.*, the boundary. As Gwilt and Haselgrove have noted

> *'Boundaries are the focus of sustained interest in current interpretations of Iron Age societies, as liminal entities between different categories of space or being.' (1997: 3)*

It is then perhaps not advantageous, nor possible, to simply discuss space in isolation and any review or analysis of space should simultaneously consider the co-dependence of spaces. Indeed to consider space in terms co-dependency alongside specific practices is as much to identify boundaries as it is to demarcate space. From an analytical perspective, boundaries can be considered transient in that they occur at the interface of space and may not even exist materially nor endure temporally, yet often such spaces may be purposely defined, monumentalised, or materialised in some manner (Ingold 2000: 192-3, Fleming 2006). Further, these boundaries or demarcations of space are not necessarily monumentalised and are therefore at times only recoverable through the careful consideration of contexts.

HEARTH AND HOME

Roundhouses were never the invention of the Iron Age, though the two have become largely synonymous in narratives of later prehistory. The houses of the later Bronze Age were originally interpreted as small hut structures (5 to 8 metres in diameter) in contrast to the massive Early Iron Age roundhouses of southern Britain (*e.g.*, the archetypal Little Woodbury, Bersu 1940). It is not the structure alone of an Iron Age roundhouse that belies a preoccupation with space. Rather, it is the temporal dimension evinced in the repeated rebuilding of Iron Age roundhouses on sites, in the same place, with the same orientation that acknowledges a greater weight placed on location, and thus space, in this period. Whilst Bronze Age people were content to relocate within a general area when rebuilding a house, individuals in the first millennium BC show a tendency towards rebuilding within the exact same place. Turning to other domestic structures common within the Iron Age, the circular form remains dominant (*e.g.*, duns, wheelhouses, and potentially brochs). Whilst the roundhouses, with their timber frames, are a product of the Late Bronze Age, these other forms of round houses, easily differentiated by their imposing dry-stone walls, often referred to as Atlantic roundhouses, are strictly Iron Age innovations (Armit 2003, Hingley 1995, Sharples and Parker Pearson 1997).

As the importance of the siting of these houses became formalised in the Iron Age, so did their orientation and internal organisation. Regardless of the myriad generalising explanations for the Iron Age preoccupation with space (Pope 2007, Webley 2007), the evidence of this fascination is certain. The internal organisation of houses illustrates preferences for how space was utilised. Rather than looking for structuring principles to explain away the evidence, it is much more productive to turn to a practice-based approach which emphasises the importance of daily routines and rituals rather than overarching dogma and cosmology. As we live we occupy places and spaces, we dwell, we exist in the world, and through these actions we create the archaeological record that is present before us.

At Longbridge Deverill Cow Down, Chadwick Hawkes examined the remains of the burnt roundhouse, House 3 (Chadwick Hawkes 1994). She found a preponderance of pottery on the southern half of the house and evidence for spindle whorls, both inside and outside the roundhouse at the west. Since the south and west provided evidence for craft and food preparation/serving activities (the pottery serves as a proxy), by default the north and east were considered to be for sleeping.

In 1991 an undergraduate thesis written by Alistair Oswald invigorated Iron Age researchers (Oswald 1991). Oswald’s thesis revealed what many had previously assumed, that for the vast majority of roundhouses in central southern Britain, entrances were orientated to the east/south-east. In a 1997 article, Oswald brought many of the same points to a wider audience, in which he also noted some of the functional constraints of roundhouses that exhibited this regular orientation. In particular, the fact that in the winter months, east facing houses would receive little to no sunlight as opposed to the many houses in the Late Bronze Age that had a southerly orientation which maximised interior light (Oswald 1997).

At Dunston Park, Fitzpatrick found evidence of a distinct division in deposition within the roundhouse between the left and right halves (Fitzpatrick 1994). He reaches the same conclusion as Chadwick Hawkes, that the half of the roundhouse with material remains represents an activity area (*i.e.*, 'living' space), as compared to the clean sleeping area. Fitzpatrick is more cautious than Chadwick Hawkes, in that he acknowledges that the placement of the artefacts need not directly reflect their predepositional use, yet he notes that there is a clear distinction between left and right to the inhabitants/abandoners of this roundhouse, and that perhaps it was the conspicuous front porch that helped to define this distinction (Fitzpatrick 1994).

Following on from the work of Chadwick Hawkes and Fitzpatrick, Parker Pearson adopted a symbolic approach to interpret the observed spatial patterning in Wessex roundhouses. He famously championed a cosmological model of Iron Age life that emphasised an appreciation of the sun as evidenced by doorway orientation and the sun-wise (*i.e.*, east to west movement) path that activities took within roundhouses (Parker Pearson 1999, 1996). The motives or structuring principles that influenced the material patterns observed in the archaeological record are far from clear. And Parker Pearson perhaps jumps to conclusions in searching for, and finding, the societal rules that structured the deposition of artefacts in Iron Age houses. It is perhaps more fruitful to focus on the individual practices (not necessarily the individuals), that left an indelible mark within a place, rather than a cosmological model that explains away myriad behaviours.

One of the staunchest critics of the 'cosmological' model of Iron Age roundhouses is Pope (2007), who critiqued Parker Pearson's work and structuralism in general. Her arguments concerning the dangers of structuralism and the haphazard application of ethnographic parallels are certainly valid. However, her criticisms of bias in Oswald's work are undermined by her own partiality in the selection of roundhouses across Britain to examine for doorway orientation (Oswald 1991). Her database of a total of 1178 roundhouses, removed those from the sites of Moel y Gaer and Garton-Wetwang Slack as apparent aberrations (due to their regular orientation), leaving only 690 roundhouses with an identifiable orientation. Of those 690, only 63%, or 435, were datable to the Iron Age. However, data for all 690 roundhouses are plotted in the article making it difficult to discern which data actually relate to the Iron Age. Pope's primary objection to previous work is that it has attempted to present a generalised picture of domestic life in the Iron Age for the whole of Britain based on evidence from central southern Britain and Atlantic Scotland in particular. Whilst this may be her impression, it is not apparent that proponents of the structured space model have promoted their work as a generic model for the whole of Britain. In battling against the inherent structuralism of the cosmological model for the Iron Age in Britain, Pope perhaps misses the point. We are reminded by Barrett that

> *'the building does not therefore encode some original meaning which the archaeologist should seek to uncover; rather it was, and it remains, a site open to signification, to be occupied and understood through practice' (1994b: 98).*

Instead of asking if cosmological concerns are structuring practice, we should be looking at how the roundhouses represent the ongoing materialisation of Iron Age peoples' actions, whilst seeking to reveal the conditions which permitted such lifeways to develop (Barrett 1981, 1997).

HILLFORTS

If we were to consider hillforts to be the monumental architecture of the first millennium BC, then we need to be aware of how they are viewed in relation to the monuments of the preceding millennia. The way we look at the spatiality of Neolithic and Earlier Bronze Age monuments is inherently different from Later Bronze Age and Iron Age formations due to the longevity of the construction of those creations. The monuments of third and second millennia BC were not planned as complete entities. Instead these monumental erections are reflections of actions and intentions that stretched across centuries (Barrett 1994b). Nonetheless, an acknowledgement of the lack of design governing certain monuments, in no way discounts the power both periods' constructions had to structure the movement and actions of people within in them.

The British Iron Age is perhaps most prominent, or obvious, in the so-called Hillfort zone where conspicuous hilltops are encircled by significant earthworks (Cunliffe 1990, 1994a, 2005, Harding 1979, 2012, Hawkes 1931, 1959). Attempts to develop an understanding of these prominent monuments have been confounded by the variation in their dating, their form, and the range of activities that appear to have taken place within them. Whilst some show evidence of augmenting earlier significant land boundaries (*e.g.*, Maiden Castle (Sharples 1991)), others appear to be constructed on virgin territory (*e.g.*, Moel y Gaer (Guilbert 1975)). Equally, some hillforts have shown evidence of both intensive and extensive settlement. Danebury presents a prime example of the latter pattern of settlement. Whilst the hillfort interior appears to be sparsely occupied, a great deal of evidence of contemporaneous extramural settlement is observed, indicative of a wider community (Cunliffe 1994b). Perhaps stranger still if we are to consider hillforts a unified and meaningful category, is that many appear to not only show limited evidence of settlement but appear to have virtually no evidence of any activity at all (Payne *et al.* 2006). They are then an enigmatic form of monument which has attracted numerous attempts to order the diversity of evidence found (Hamilton and Manley 2001, Harding 2012, Cunliffe 2005). For instance, Cunliffe has attempted to craft a cohesive narrative of hillfort development that has the phenomenon fully rooted in the Iron Age. Though hillforts are frequently considered as a single phenomenon, their appearance (both spatially and temporally), construction, and subsequent development often differ greatly. Just as the hillforts are not representative of a uniform class of monuments, the manner in which they evidence a preoccupation with space is not uniformly articulated.

Moel y Gaer, Flintshire

The site of Moel y Gaer, Rhosesmor in North Wales is an example of a hillfort showing a period of settlement demonstrating early 'urban planning' (Guilbert 1975). It was not constructed upon the site of an earlier prehistoric settlement and its enclosure is firmly dated to the first millennium BC (*i.e.*, 580 ± 90 bc Guilbert 1975, Cunliffe 2005). The initial phase of occupation at Moel y Gaer was unremarkable in relation to other Iron Age settlements, illustrating gradual growth over time (Guilbert 1975, 1976). However, Phase 2 witnessed the enclosure of the hilltop with a timber-frame rampart as well as a new organisation of the settlement interior, demonstrating planned, (*i.e.* predetermined or designed) use of space. In particular, there was a regular alignment of the roundhouses contained within, characterised by an 'obsessive desire to orientate the round-house entrances towards the east' (Guilbert 1975: 205) (Figure 4.1), as well as

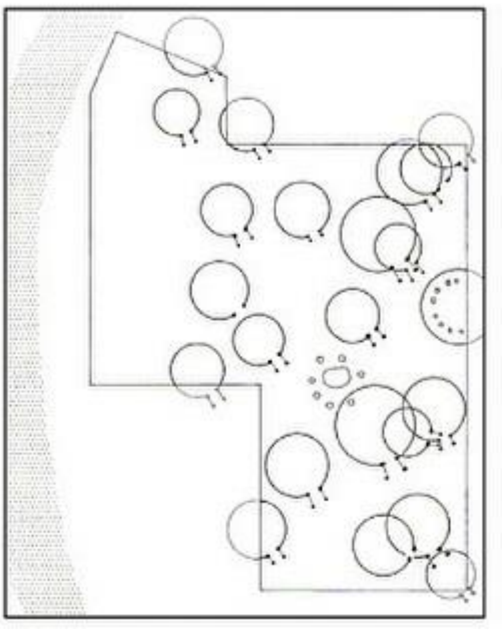


Figure 4.1 Plan of the interior of Moel y Gaer hillfort, Rhosesmor, North Wales (image from Guilbert 1976).

an arrangement of twenty-six four-post structures in rows orientated parallel to the ramparts. The regular grid observed for the rectangular structures at Moel y Gaer is not unique and is also noted at Crickley Hill, Croft Ambrey, Danebury, and Ffridd Faldwyn (Guilbert 1975, Cunliffe 1984a, Cunliffe 2005). However, it is the pairing of the orderly arrangement of four-post structures and the consistent orientation of the roundhouses that sets Moel y Gaer apart from other first millennium settlements. Combined with the evidence that these structures were representative of a comparatively short period of occupation, the indication that this phase is illustrative of planned settlement is fairly concrete.

Cadbury Castle, Somerset

Cadbury Castle in Somerset is another hillfort essentially constructed *de novo* in the first millennium BC, with only minor evidence of prior settlement in the area (Alcock 1972, Barrett *et al.* 2000). However, in some respects Cadbury is quite dissimilar to Moel y Gaer, in that its interior belies any sense of predetermined, or even consistent, order in the patterning of its roundhouses. Instead, Barrett *et al.* (2000) have remarked that the organisation of dwellings in the interior of Cadbury is perhaps indicative of a residential community that was not fully integrated. The apparent value placed on personal, rather than communal, space is evidenced by the varied orientation of roundhouses which afforded the residents 'the feeling of a localised, almost private range of spaces immediately in front and to either side of the house entrances' (Barrett *et al.* 2000: 320). Cadbury may not represent an early example of town planning, yet its construction does still evince a marked preoccupation with space and how it might be experienced. The hillfort is somewhat unusual in having three distinct entrances (Figure 4.2). Despite what might appear to be rather open access to the site, these entrances present strikingly different encounters with the interior of the hillfort. Upon entering Cadbury Castle through any one of the gates, one is unable to view the entirety of the site (Figure 4.2). Instead, the entrances have been sited in such a way so as to take advantage of the natural topography of the hill, and thus present three distinct interior spaces to a visitor to the site and

> *'[a]n understanding of the overall organisation of the settlement could only have been pieced together out of the sequence of movements an inhabitant may have made over the hill' (Barrett* et al. *2000: 153).*

Interestingly, atop the plateau, is found evidence of an 'industrial' area with debris from bronze and iron working dating to throughout the Iron Age (Barrett *et al.* 2000: 291-298). The presence of these activities on the centrally located plateau immediately

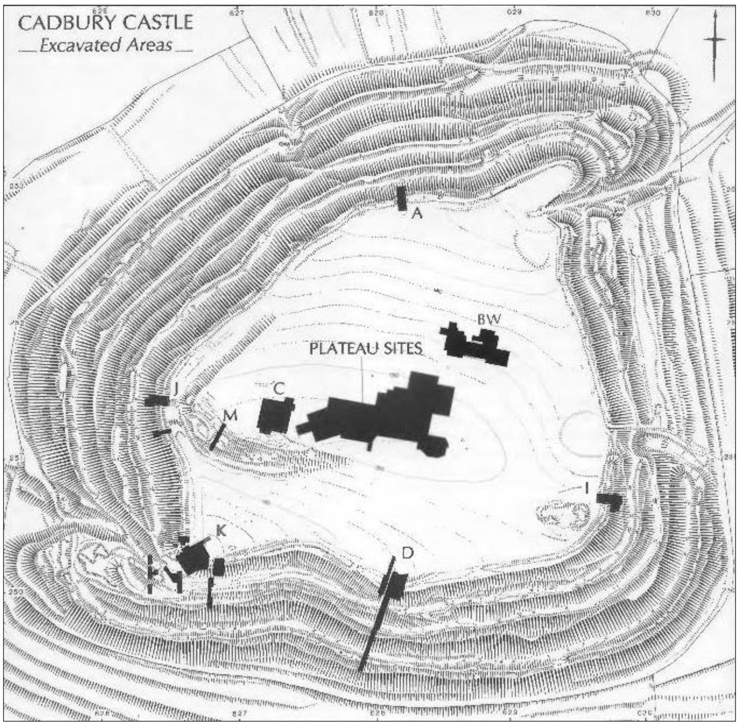


Figure 4.2 Plan of Cadbury Castle, Somerset with locations of excavated areas (image from Barrett *et al.* 2000: 16).

evokes the idea of spectacle—with furnaces alight for all to see. However, the circumscribed access to the hilltop, and its interior, would necessarily restrict access to the plateau, limiting the metallurgical performance to a select community.

The enclosure of the hilltop created the place that was Cadbury Castle rather than the act of constructing houses in it (Barrett *et al.* 2000: 83). The dwellings were important, but the real control of space here is demonstrated by the access to the hilltop, and the varying restricted view of the plateau that these entrances afford. The roundhouses and their respective orientation speak more to the idea of family rather than broader community that the hillfort itself illustrates.

Maiden Castle, Dorset

Maiden Castle in Dorset represents an iconic and at the same time, unusual hillfort. The well-known first millennium BC settlement has its origins in the Neolithic, in the form of an earlier causewayed enclosure in the midst of a ritual landscape of other monuments. The evidence of occupation in the area is relatively uninterrupted from the third millennium onwards and is indicative of a lingering import placed upon this location within the region (Sharples 1991, Wheeler 1943). Though Maiden Castle itself is not located on a hilltop proper, it is sited at an important point in the landscape in terms of river valleys and access to the interior of the fertile country side. The present monument had much in common with its forebears, in terms of the manner in which it came to be. Maiden Castle as it exists today is the product of millennia of building and dwelling within this place. There was never a fixed construction plan for the hillfort that is witnessed today (Sharples 1991, *contra* Wheeler 1943). The extended hillfort that is preserved today was the product of labour in the mid-first millennium BC that was both cognisant and respectful of the past constructions on the site (Sharples 1991, 2010). Maiden Castle was apparently not densely occupied at any point in time based on the excavations of both Wheeler (1943) and Sharples (1991), yet is remarkable for having noteworthy metalworking activity both within and at the entrance to the hillfort in subsequent phases. The metalworking at the eastern entrance to the hillfort (Figure 4.3)

Figure 4.3 Aerial view of the eastern entrance of Maiden Castle, Dorset (photograph from Allen 1934).

is significant for its dramatic, and potentially unsafe, placement at the gateway to the interior of the site. The layer of ash that was produced by these activities was initially interpreted as the product of a Roman attack on the fort, but is instead more likely to be the product of considerable iron working (Sharples 1991: 100). The level of evidence of this practice illustrates the performative power of these practices and how the resultant debris conjures up images of fire and brimstone. The level and variety of occupation of Maiden Castle is debatable. The areas of excavation that provided the majority of settlement evidence for the site were the contiguous Wheeler's Site D and Sharples' Trench IV. Both trenches produced significant evidence of metalworking, and it seems more likely that the roundhouses and dwellings here represent a craft quarter of sorts rather than a typical domestic settlement. Therefore it seems hasty to make comments upon the character of domestic structures within the hillfort as Sharples attempts to do (1991: 86).

Danebury, Hampshire

Danebury in Hampshire is one of the most well-studied hillforts due to the extensive research programme directed at mapping the hillfort and its environs (Cunliffe 1984a, 1984b, 1994b, Cunliffe and Poole 1991a, 1991b). For almost two decades, Danebury was systematically examined under the direction of Cunliffe, where over fifty percent of the interior was excavated and carefully mapped. Similarly to others of its monument class (*e.g.*, Cadbury Castle and Moel y Gaer), the locale in Hampshire was virtually unoccupied prior to the appearance of the hillfort around the seventh century BC. The extensive excavation of the hilltop has produced an unrivalled picture of domestic settlement within a hillfort, though one must be careful not to suppose that Danebury represents the norm for this heterogeneous class of monuments. In total 73 circular structures were revealed across the interior, laid out in a manner that was respectful of

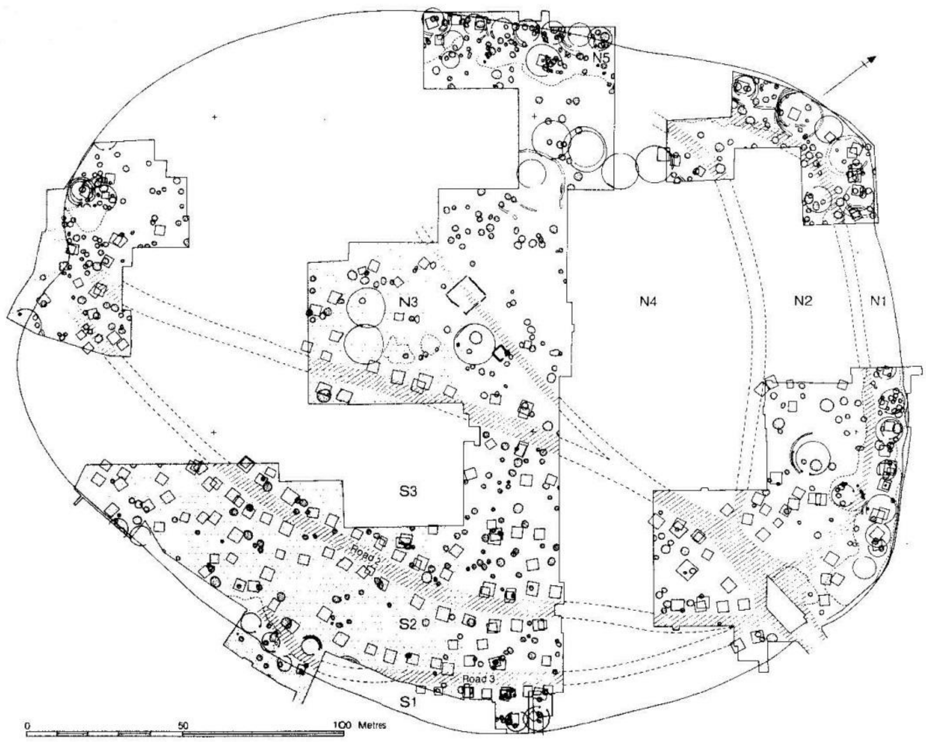


Figure 4.4 Plan of the interior of Danebury hillfort, Hampshire in the Late Period of the site (image from Cunliffe and Poole 1991a: 236).

roads that criss-crossed the space within the ramparts (Cunliffe 1984a, Cunliffe and Poole 1991a) (Figure 4.4). In contrast to the interior regularity exhibited by the roundhouses of Moel y Gaer, the domestic structures of Danebury are arranged rather haphazardly with no appreciable organisation. Great variation in doorway orientation was also observed, though this lack of discernible patterning in the arrangement of the domestic structures could be partially attributable to the differing levels of feature preservation within the hillfort (*i.e.*, the periphery of the intramural area was preferentially preserved in the lee of the ramparts where debris often covered these features) (Cunliffe and Poole 1991a: 38-39). However, there was spatial regularity noted in the layout of four- and six-post structures within the hillfort. These structures are commonly located along the sides of the roads that traverse Danbury's interior (Cunliffe and Poole 1991a: 114). Further, there does appear to be some sort of preference for structures with hearths to be located within the lee of the eastern inner earthwork, whilst ovens are more uniformly distributed across the site (Cunliffe and Poole 1991a: 141-142). Analysing all structures together, Cunliffe and Poole (1991a: 239) found significant differences in the patterns of occupation between the south and north sections of the site, for all periods, as determined by features' locations in relation to the main road that ran between the eastern and south-western entrances. This distinction between the two halves of the hillfort was illustrated by the range and abundance of post-built structures, as well as the treatment of the ramparts.

Hengistbury Head, Dorset

The site of Hengistbury Head in Dorset is a promontory fort that forms one side of protected Christchurch Harbour. The Head has been the site of human activity from the Upper Palaeolithic (*ca*. 12500 BC) onwards (Cunliffe 1987a, 1987b). In the first millennium BC the Head was effectively enclosed by the construction of the Double Dykes across the narrowest extent of the spit of land leading to the high point of the Head at Warren Hill (Bushe-Fox 1915, Cunliffe 1987a). Whilst there is little evidence of internal organisation in the Early Iron Age settlement of the Head, a preference for orientating penannular ditches in a south-easterly direction is observed (Cunliffe 1987a: Ill. 61). The promontory fort is more significant spatially in terms of its location within the wider landscape. Sitting at the mouth of the Rivers Avon and Stour, Hengistbury Head was the gateway, and perhaps gatekeeper, to the region's interior (Figure 4.5). And it is atop the cliffs at the centre of the Head that the most intriguing evidence is found of highly conspicuous iron metallurgy. The majority of Iron Age settlements do exhibit evidence of iron working, as previously mentioned, yet Hengistbury Head importantly reveals metallurgical features and debris potentially indicative of the primary production of iron. The excavated metallurgical features (*i.e.*, multiple hearths, Cunliffe 1978) strongly support the conclusion that smelting took place at Hengistbury, yet the slag evidence recovered to-date cannot confirm this supposition. It is likely the exact arena of production has been lost at the site due to later quarrying of ironstone and/or natural

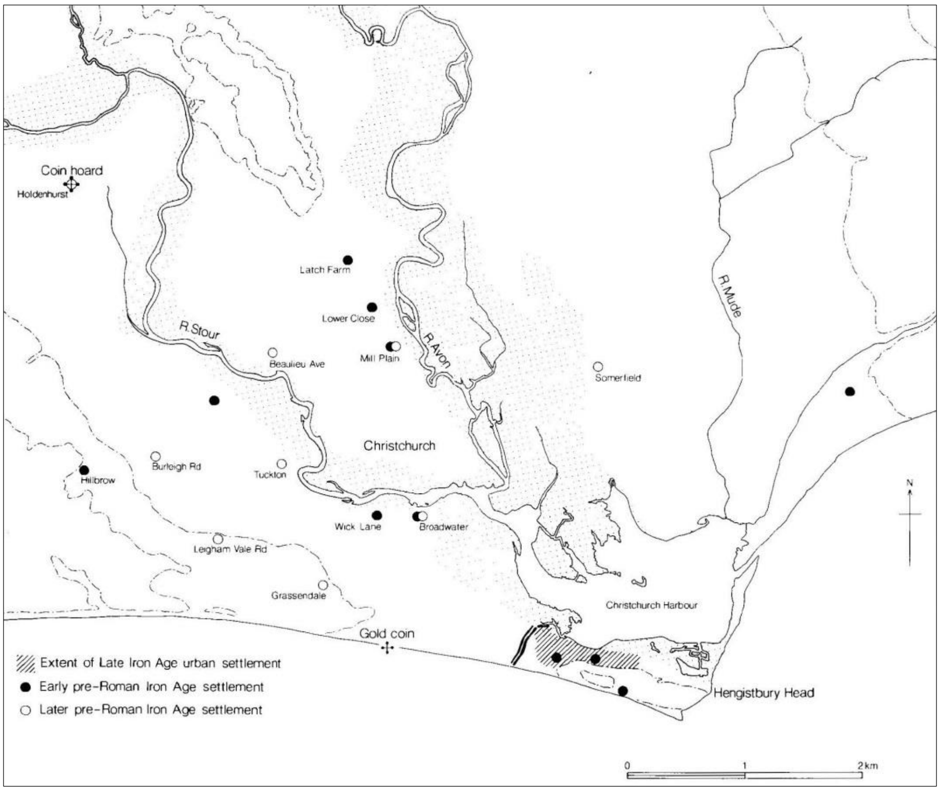


Figure 4.5 Map showing Hengistbury Head, Dorset in relation to geographical features and contemporary sites (image from Cunliffe 1978: 336).

erosion (Salter 1987: 202). Thus, at an entrance to the country, a defended site, utilised—practically or symbolically—a local resource (procured from within the promontory fort itself) to openly display its productive power (Cunliffe 1987a, Salter 1987, Salter and Northover 1992).

BOUNDARIES AND BOUNDING

> *'[N]o feature of the landscape is, of itself, a boundary. It can only become a boundary, or the indicator of a boundary, in relation to the activities of the people (or animals) for whom it is recognised or experienced as such' (Ingold 2000: 192-3).*

Bowden and McOmish, in a pair of articles in the late 1980s, began to tackle the issue of the increasing focus on boundaries and enclosure in the Iron Age (1987, 1989). They found the 'defensive' works of the Iron Age to be analogous to the 'excessive monumentality' of the ritual monuments of the Neolithic and Earlier Bronze Age, rather than simple functional barriers. These 'defences' were no more than the physical witness of the conspicuous consumption of resources by individuals in later prehistory. In fact for Maiden Castle, Bowden and McOmish saw the multivallation as counterproductive to the defence of the settlement as 'the outer ditches create 'dead ground' and the massive inner ditches totally isolate any defenders of the outer ramparts' (1987: 77). The pair also remark that the focus on the internal spaces of hillforts for ritual importance may have neglected the import that the defences themselves held; 'the morphology and topography of the ramparts themselves may indicate ceremonial activity' (1989: 13). Hill sees hillfort defences as demonstrating an 'increasing sophistication in the control of space; the elaborations intervening to constrain the way in which the space of the hill-fort was encountered and 'read' increased through time' (1996: 110). The defences ultimately serve to control engagement with the site, rather than merely limiting access.

SUMMARY

Heretofore this chapter has highlighted the academic effort devoted to the use of space in the Iron Age. Whilst the roundhouse has been seen by some as a space which is structured by routine activities (*e.g.*, Fitzpatrick 1994, 1995, Giles and Parker Pearson 1999, Parker Pearson 1996), others, chiefly Barrett, have emphasised that the first millennium BC witnesses significant shifts in the way space is used beyond the level of domestic structures. In particular, how 'historic' landscapes are incorporated in the remodelling of the landscape shows an awareness of and preoccupation with space at a regional level. For instance, Barrett (1999) has drawn attention to the significant efforts made in land division, especially in the peripheral areas relative to the old centres of earlier Bronze Age and Neolithic ritual life.

The interest in and the apparent significance of space in Iron Age studies has been comprehensively argued for and established by a number of scholars. For the most part these studies have been based on a moderate number of investigations that have mapped finds distribution or have focused on the orientation of entrances with inferred relevance for light-fall on specific zones. The overarching conclusion, that Iron Age space is used in a meaningful and rigorously structured manner is a very significant and meaningful result. It is then a little surprising that more studies have not aimed to explore this phenomenon in more detail and through material not yet examined. It is with these issues in mind that the thesis sets out to address not only a framework to explore a so far underrepresented mode of practice but to also extend the theoretical context within which such results might be more fully considered.

This chapter has sought to define the manner in which spaces has been incorporated in to Iron Age narratives by archaeologists over the past three decades. It is apparent that space is a concept which needs multiscalar approaches (see chapter 5) yet these scales centre on the human as the vehicle through which cultural understandings are realised and acted upon. As such it is through such a scale that the projected analysis in this study will advance our understanding of how places come into being and are formalised.

Chapter 5. Characterising Space

INTRODUCTION

In the previous chapters we have established the theoretical concerns which underlie our characterisation and understanding of space and how it was employed in prehistory. Specifically, we examined how such an awareness of space has been articulated in Iron Age Britain and thus the reasons why space has become a research priority in Iron Age studies. This chapter now turns to more practical methodological concerns and addresses how space may be characterised and what the implications are of spatial analyses across a variety of scales. This exploration takes us from the very large, entire landscapes, to atoms residing in a specific context. Across this scale of analysis a range of sub-disciplines come to bear on studies, ranging from landscape archaeology to soil ecology. In moving from whole landscapes to particular atoms we transit scales which are both beyond and below human perception. The abstracted mapped ritual landscape of Neolithic Wiltshire, or the Late Bronze Age field systems of Dartmoor are unlikely to ever have been perceived as a whole in the past, as the archaeology student does today (Barrett 1994b, Fleming 1988). On the other hand, enhanced copper concentrations in soil are unlikely to have been realised, at least causally, by the inhabitants of an Iron Age forge. Between landscapes and soil chemistry, arguably both abstracted realities, there exists a scale of analysis which is realisably human (Table 5.1). Architecture and portable finds occur at a scale which is comprehensible at normal levels of perception (Jones 2002) and in this a tangible connection can be found with our forebears. This is an important point and should not be forgotten, as while abstracted scales of analysis might be capable of producing interesting and significant datasets unless they are reworked at the human scale, they are unlikely to be used in the production of meaningful histories.

In reviewing the scale at which space has been scrutinised and differently characterised this chapter moves across these scales of analysis with the intention of highlighting and critiquing three main points

- The techniques used to characterise space at a particular scale
- The types of data produced by such techniques and what these data in turn represent
- How such data are used and the types of history written with them

Context	Scale	Perception	Practice	Techniques
Landscape	macroscale	Above perception	More determining of practice	Aerial photography, field walking, geophysics, LiDAR
Site/Settlement				Aerial photography, earthwork surveys, geophysics, space syntax
Architecture /Structure	Human scale	At perception	Level of practice	Space syntax, inhabited approaches
Small finds				Distribution maps
Microdebitage	microscale	Below perception	More determined by practice	Magnetic susceptibility, flotation
Soil matrix				Geophysics, geochemical analysis

Table 5.1 Techniques utilised in the characterisation of space at differing scales.

LANDSCAPE

The field of landscape archaeology is too broad to cover in any detail herein. For the purposes of this chapter we will only briefly discuss the major techniques in use for characterising space at the scale of the landscape. The term 'landscape' is contentious, with myriad definitions and meanings for those that study it (Ingold 1993, 2000, Tilley 1994, Fleming 2006). Irrespective of these differences in connotation, it can be acknowledged that landscape exists at a level generally beyond human perception. As Fleming (2006: 269) eloquently remarks, 'pre-Enlightenment humans would not have 'gazed' upon the world in the Cartesian manner of late twentieth-century landscape archaeologists'. That is not to say that humans do not possess an awareness of the landscape(s) they inhabit, but that whilst features of these landscapes may structure space and individuals' relationships with those spaces, seldom can one be cognisant of the totality of the landscape (*i.e.*, the *gestalt* of its' features).

Approaches to characterising space at the landscape level, have been dominated by the bird's eye perspective afforded by aerial photography, and the ability to translate survey data into effective maps (Aitken 1974, Aston 1985). Field-walking has been used in much the same way to characterise landscape through the production of detailed notes and plans, later adapted to create maps of earthworks or entire regions. The advent of computerised data-loggers paired with detectors for a variety of geophysical methods (*e.g.*, magnetometry, resistivity, magnetic susceptibility, ground-penetrating radar, *etc.*) in the 1980s allowed for the quick survey of extensive areas, again with the aim of mapping both for prospection and characterisation (Clark 1996, Gaffney and Gater 2003). These data have formed the basis for Ordinance Survey (OS) maps and the old

Royal Commission on the Historical Monuments of England (RCHME) plans—now a part of Historic England—as well as the myriad maps in archaeology textbooks that have allowed generations to examine landscapes from this lofty perspective. However, our bird's eye view on past landscapes both privileges and hinders us in our understanding of how these places would have been inhabited in times past. The observations on the spatial arrangement of sites and landscape features, seemingly objective reflections on the patterning of people in space, often lead to narratives of territories, population pressure, and conflict (Cunliffe 2004, 2005, Fleming 1971, Hodder and Orton 1976).

Since the 1990s, Tilley (1994) and others have challenged this top-down view of the landscape and have endeavoured to take a more phenomenological and inhabited approach in their studies (Edmonds 1999, 2004, Cummings 2002, Cummings *et al.* 2002, Cummings and Whittle 2004, Ingold 2000). The phenomenological approach is typified by its rejection of representations of space and its assertion that the landscape cannot be objectively known and only subjectively experienced. Whilst experiential engagement with the landscape is laudable for bringing our perspective back to human scale through our embodied interaction with space, the data produced through this method are often difficult to reconcile with existing evidence (Fleming 2006).

SITE/SETTLEMENT

Studies of sites and settlements for Iron Age Britain, in particular, have been dominated by the concept of site-types: hillforts, banjo enclosures, brochs, *etc.* Though functional, these site-types themselves have often been crafted to include specific categories of features to accompany carefully constructed narratives (*e.g.*, hilltop enclosures vs. hillforts in southern Britain) (Cunliffe 2005). This preoccupation with classification has led to approaches that often fail to understand the characteristics of each individual site, instead neatly assigning the past to predetermined categories. In viewing sites as types, we can overlook significant differences between settlements that may otherwise fit into the same broad category. For instance, both Danebury and Maiden Castle are examples of multivallate hillforts. However, the former sits atop a hill that saw limited occupation prior to the first millennium BC whilst the latter represents the expansion of a substantial Neolithic enclosure during the Iron Age (Wheeler 1943, Sharples 1991, Cunliffe 1984a). Few would confuse these two iconic hillforts, yet for many other similarly categorised sites their individual characteristics are subsumed by the inviolate type.

Site prospection using geophysical methods is regularly undertaken with the aim of assigning unexcavated features to the aforementioned typological regime. Together visible and buried sites are then placed on to distribution maps often in support of arguments concerning territory and political influence. Further, classification of settlement earthworks has led to a preoccupation with determining the defensive character of sites in the first millennium BC (Cunliffe 2005), which has more recently been countered by less bellicose interpretations that emphasise the communal engagement involved in the construction of earthworks (Sharples 2007, 2010).

Others have chosen to look within settlements to the particular arrangement of structures to better understand their function in the past. Hillier and Hanson (1984) developed space syntax as a method of analysing how humans moved about space, both at the site and structure level. Though adept at showcasing how past people *could* have navigated a site, insights afforded by the space syntax approach are little more than least-cost pathways. These results though an accurate reflection of how a space could have been accessed, do not elucidate how these spaces were actually inhabited and negotiated in the past.

Coles and Minnitt’s (1995) thorough reappraisal of Bulleid and Gray’s (1911) excavation of Glastonbury Lake Village provides a prime example of the ability to examine space at a site level from more than just a typological perspective. Their analysis of the progression of building and use of the settlement allows us to understand how the site was inhabited at particular times over the course of its occupation. The excavations of Bulleid and Gray (1911, 1917) recorded level after level within the individual mounds of the lake village. Though they mapped the artefacts, distributions were left untethered temporally with seldom a mention of their specific placements within the stratigraphy of the site. Conversely, the carefully phased maps of the lake village produced by Coles and Minnitt (1995) show not simply how the space could have been utilised in the past, but in fact how it *was* occupied by its inhabitants. This work allows us to better interrogate the distribution maps of Bulleid and Gray (1911, 1917) to begin to understand how practice, in particular that of metalworking, was organised around the site both spatially and temporally.

ARCHITECTURE/STRUCTURE

This broad category includes all structures and features within a site including houses, post-holes, pits, furnaces, hearths, *etc*. All of these features structure movement and engagement within space. Yet, to date production features (*e.g.*, furnaces, hearths, kilns, *etc.*) rarely, if ever, have been considered 'true' architecture despite their manifest ability to enable and constrain the actions of the human body. Rather than debate definitions of architecture, we are simply acknowledging the impact that all these features have on the human experience in space. Categorisation of architectural space has been dominated by typologies and distribution maps. When studying the distribution of architectural features across a site, the lines begin to blur between the structural and settlement scale. Structures may be studied on their own yet these features largely gain most importance in their associations with other structures as well as artefacts.

We need to move away from the theoretically naïve techniques of spatial syntax (Hillier and Hanson 1984) and define new methods for recording and interrogating structural/featural/architectural data. Access analysis (*i.e.*, spatial syntax within structures), though useful for elucidating differences in building plans that are otherwise difficult to perceive from drawings alone (Foster 1989a, 1989b), is essentially another typological tool that serves only to categorise structures in terms of the supposed power they exert in controlling the movements of those who enter them. Furthermore, this interest in controlled access to space sees architecture as a disembodied force for preventing action as opposed to the very means of enabling practice within a particular locale.

There is a need to focus on the human body and how individuals have a recursive and reflexive relationship with the structures we inhabit (Ingold 2000). Using the human body as our frame of reference we can begin to perceive how a space was inhabited (Tuan 1977). The example of a Neolithic house at Skara Brae, Orkney is particularly adept at illustrating how architecture can enable movement within, rather than simply access to, space. The stone slabs at the entrance are subtly placed to direct the flow of movement around the house in an anti-clockwise direction rather than allowing an individual entering the house to select his path (Parker Pearson and Richards 1994b: 42). Whilst this relationship between the human body and the built environment has been realised for some time in archaeology, it is usually only understood for structures that people inhabit internally. This category needs to be expanded to include technological architecture. Features such as furnaces and kilns are unusual structures that are not inhabited internally but do serve to structure action. Through their use the transformative environments in and around them are negotiated by craft practitioners. In much the same way that paving stones can direct movement, the alignment/placement of a furnace or kiln structure within a space will have a great impact on how individuals engage with and are bound to these features during the process of production. Whilst temperatures directly in front of the tapping/stoking hole of a furnace/kiln can easily exceed 500 °C, these extreme conditions quickly taper off, making most other positions around the structure effective working space. The height of the furnace structure also significantly impacts on the diffusion of heat from the source. Shaft furnaces of a metre or more in height are easily approached as heat radiates upwards, smaller squatter furnaces on the other hand are much better at radiating heat outwards, and perhaps this very nature would make them ideally suited to act as multi-purpose thermal features within a domestic setting. Furnaces and other architectural features need to be examined in detail to adequately understand how past individuals would have interacted with them, both during use and dormancy. Whilst in use, there is an array of material that we can investigate, through analytical means, to estimate temperatures acquired, heat flow and air flow, *etc.* In accommodating pyrotechnical structures as architecture we open them up for what, in craft studies, would be novel forms of analysis. This analysis will not be akin to the architectural analysis of passageways and entrances and or orientation in space, be that public or private, but will acknowledge differing aspects of material constraints, so often defined so precisely in technology studies, and which act as limiting parameters in our understanding of the spatiality and temporality of craft practice.

SMALL FINDS

It is worthwhile to be cognisant of Bradley's amusing observation that 'successful farmers have social relations with one another, while hunter-gatherers have ecological relations with hazelnuts' (1984: 11). Why do we automatically examine finds within differing frames of reference when they come from the distant, not so distant, and near past? Much of the literature on intra-site spatial analysis of artefacts and architecture comes from Palaeo- and Mesolithic sites, or alternatively from ethnographic peoples/sites that are seen as proxies for our hunter-gathering past (Binford 1978, 1987, Kroll and Price 1991). With the advent of substantial (*i.e.*, permanent) architecture on sites, the importance of artefact spreads is often ignored in favour of these more visible attributes.

Despite the presence of substantial architecture during the first millennium BC, the importance of artefact distributions cannot be discounted. The spread of artefacts across a site gives a tantalising glimpse of past activity areas, whether they be areas of production or discard. The majority of spatial studies of archaeological sites have focused either on the inherently limited technique of access analysis (Hodder and Orton 1976, Hillier and Hanson 1984, Cutting 2003) and the investigation of the artefact distributions (Leroi-Gourhan and Brézillon 1966, Binford 1978, 1983, 1987, Audouze 1987). Mapping the distribution of artefacts across sites to analyse inter- and intra-group differences between structures and phases is routine (Fisher 1985, Morris 1996, Schwanen 2007), yet still little has been done to link up these artefact spreads with agency-centred approaches that seek to understand the formation processes preserved within these distributions. Instead, artefacts have commonly been used as proxies for past practices and technologies, with a tendency to presuppose a one-to-one relationship between artefact distributions and the locus of activities that used these artefacts (Morris 1996). Not enough consideration of depositional processes (though there has been extensive study of post-deposition processes) has been taken to better understand how these artefacts enter the archaeological record. Thus, though this might seem an outdated approach to the spatial analysis of metalworking, in combination with other techniques it can be quite nuanced and powerful for revealing arenas of past actions.

Though due to the portability of artefacts, they have the potential to aid us and lead us astray at the same time. There is an inherent ambiguity to small finds, their distribution is undoubtedly structured by human action within a site, yet their portable nature allows them to be moved between myriad contexts across space and time (*e.g.*, through curation or cleaning episodes).

MICRODEBITAGE

Microdebitage represents both a scale and category of evidence unique to a few productive activities. In particular, iron smithing produces microdebitage in the form of slag droplets and hammerscale through the percussive action of forging an iron bloom or billet (Dungworth and Wilkes 2009). The sparks that are commonly observed in a smithy as the smith strikes the red hot metal are in fact miniscule bits of iron oxide that fall to the ground and are subsequently ignored. Hammerscale is most often detected through magnetic susceptibility surveys due to the resultant enhanced induced magnetism observed in soils (Doonan and Mazarakis Ainan 2007) or through flotation of soil samples (Bayley *et al.* 2008), often advantageously discovered by environmental archaeologists. Veldhuijzen (Veldhuijzen and Rehren 2007, Veldhuijzen 2009a, 2009b) has worked on refining methods for hammerscale collection on site using grids and magnets to map densities in the field. Most reports that do mention the presence of hammerscale simply record the presence and absence across a site rarely using this class of material to identify activities in space. This lack of awareness of the utility of microdebitage for understanding past practice is unfortunate considering Mills and McDonnell's (1992) study of hammerscale distribution that recognised the utility of this form of evidence in elucidating use of space within a smithy decades prior. More recently Jouttijärvi's (2009) analysis of hammerscale distribution within an experimental smithy has shown how microdebitage can capture actions in a manner similar to Binford's (1978, 1987) discard patterns around a hearth.

SOIL MATRIX

The geophysical techniques mentioned earlier have been predominantly used for site prospection, yet despite their ability to generate high-resolution data (<1m), they have seldom been used to analyse the spaces between 'features' at both prospection and excavation stages. Yet within settlements and structures, geophysical and geochemical methods, have the capacity to resolve activity areas in a manner that is markedly less ambiguous than the mapping of portable finds.

Metalworking activities are transformative pyrotechnological processes and as such tend to 'imprint' soil contexts to a greater degree than other human activities. The vast

	Copper-base	**Ferrous**
Ore roasting	600-850	600-850
Matte production	≥800	
Smelting	1100-1250	1100-1250
Casting	1100-1250	
Smithing		900-1200

Table 5.2 Operating temperatures in °C for a variety of metallurgical activities under consideration (Craddock 1995, Tylecote 1986).

majority of metalworking activities take place between 700-1300 °C (Table 5.2); a significant temperature range for affecting change in soils (largely in magnetic properties) making these processes ideally suited for study by geophysical techniques that measure magnetism.

Other high temperature features (*e.g.*, ceramic kilns, hearths, glass furnaces, ovens, bonfires) produce notable magnetic susceptibility enhancements in soils. Metalworking and other high temperature activities routinely reach temperatures greater than 200 °C and are therefore capable of enhancing the magnetic susceptibility of available iron oxides, and also regularly achieve temperatures above the Curie Points for iron oxides (*i.e.*, 565-675 °C). Above this point, thermoremanent magnetism is induced, which is detectable by magnetometry (Tylecote 1986, Aspinall *et al.* 2008, Gaffney and Gater 2003). The magnetic susceptibility of soils is related to both iron oxide concentration and type of oxides present (Tite and Mullins 1971), yet copper-alloy and ferrous metallurgical activities both have the capacity to contribute iron oxides to the system through ore, matte and slag, as well as metallic iron, which can therefore greatly increase the potential magnetic susceptibility of soil. As long as the soil has a significant fraction of iron oxides the thermal activities associated with smelting, smithing, and other high temperature metalworking endeavours will leave geophysically detectable traces in the ground (Weston 2002).

There are two distinct types of magnetism that are affected by pyrotechnical processes. The first, remanent—in particular thermoremanence (TRM)—involves the alignment of magnetic moments within the minerals present in the soil (Aspinall *et al.* 2008). The earth's magnetic field alone cannot induce this type of magnetism, but when minerals, especially iron oxides are heated above their Curie Points, TRM is induced. Further, the alignment fixed within the minerals by TRM is the same as that of the earth's field at that time and allows for potential archaeomagnetic dating of thermal features (Crew 2002). The second type of magnetism, magnetic susceptibility, is enhanced via two related processes, heating, and 'fermentation' (Le Borgne 1955, 1960). The experimental work of Le Borgne revealed the mechanism by which the magnetic susceptibility of topsoil is preferentially enhanced. Additionally, he identified situations that preclude significant magnetic enhancement or in which anthropogenic enhancement can be masked by underlying geology. Both heating and fermentation are essentially redox reactions that involve the chemical alteration of iron oxide minerals. As soil is heated above 200 °C in a reducing atmosphere the antiferromagnetic iron oxide hematite (α-Fe_2O_3) alters to ferrimagnetic magnetite (Fe_3O_4), then as it cools the mineral re-oxidises to ferrimagnetic maghemite (γ-Fe_2O_3). The same reaction can occur through microbial agency to reduce and then subsequently oxidise the iron oxide minerals within a soil (*e.g.*, in middens or graves) (Linford 2004).

Geophysical Techniques

Magnetometry

Magnetometry is predominantly used for site prospection due to its ability to resolve subsurface features, especially, pits and ditches, rapidly over extensive areas. The technique is less adept at detecting buried walls unless they are constructed of particularly magnetic stone (*e.g.*, granite or basalt) or if they consist of fired clay/mud-brick (either purposefully or through conflagration). Magnetometry is strictly a passive technique in that it detects both remanent and magnetic susceptibility in the presence of the earth's magnetic field. (Remanent magnetism is always measurably magnetic and magnetic susceptibility is only magnetic when induced in the presence of a magnetic field. However, the earth's magnetic field is always 'on' and therefore even as a passive technique, magnetometry detects magnetic susceptibility (Clark 1996).) Magnetometry was first used by Aitken *et al.* (1958) for detecting buried Roman kilns. It was quickly discovered that the technique was particularly adept at detecting buried features, not just those that had undergone sustained burning, which are magnetically enhanced due to their preferential filling with topsoil. Modern survey is conducted using fluxgate gradiometers, which instead of measuring the actual magnetic response, record the difference observed between two sensors placed either 0.5m or 1m apart vertically.

The problems of using magnetometry for prospecting and investigating metalworking sites have long been noted (Crew 2002). These issues mainly centre round the presence of large concentrations of slag and/or metallic iron on sites that can 'saturate' surveys by presenting numerous spikes in data that mask underlying variation. Magnetic susceptibility is prone to the same issues but is also more sensitive in terms of locating spreads of hammerscale. That said, large slag piles are generally located away from the traditional centres of productive activity on site. Further, few examples of metalworking are intensive for prehistoric Britain (*contra* Crawcwellt, (Crew 1998)) and thus seldom exhibit the same magnetic 'noise' created by sustained large-scale production.

Magnetic Susceptibility

Magnetic susceptibility is a technique often used in conjunction with magnetometry as a tool of confirmation in terms of resolving potential archaeological features. This technique can be applied both *in situ* and *ex situ*, though the preparation time involved in measuring magnetic susceptibility in the laboratory is generally unnecessary in light of the speed at which analysis can be undertaken in the field. Typically, magnetic susceptibility surveys are conducted at much lower resolution than those of magnetometry and English Heritage guidelines only suggest a maximum resolution of 10x10m (Jones 2008). Magnetic susceptibility is a sensitive technique that is underappreciated for its ability to map past human occupation and activity. Whilst magnetometry is adept at locating shallow buried features, magnetic susceptibility can readily identify areas of past activity resulting in magnetic enhancement that are often less visible (*e.g.*, byres, middens, *etc.*) (Aspinall *et al.* 2008). In contrast to magnetometry, magnetic susceptibility is an active technique that involves the application of magnetic field to induce magnetism in a sample.

Geochemical Techniques

Geochemical analysis of soils using both *in situ* and *ex situ* techniques has increasingly been used for site prospection and more importantly for the study of intra-site areas (Cook *et al.* 2010, Milek and Roberts 2013, Ramsey and Boon 2011, Salisbury 2013). The initial application of geochemical techniques to the study of archaeological soils and sediments was in the form of phosphate analysis due to its recognised relationship between human activity (largely accumulated through human and animal waste) and its concentration in soils (Arrhenius 1931, 1934, 1963). From its earliest applications, the study of phosphate concentrations on sites has dominated the literature on geochemical approaches to sites. Over the past few decades Barba in particular (Barba and Bello 1978, Barba 1986, 1987a, Barba and Manzanilla 1987b, Manzanilla and Barba 1990, Barba and Ortiz 1992, Middleton *et al.* 2010) has expanded the repertoire of geochemical approaches and questions, studying a variety of activities that impact soils and the elements that can serve as the proxies of these activities. The field of household archaeology has been at the forefront of the application of geochemical techniques to the analysis of soils and sediments, aimed at investigating activity areas both within and without of domestic structures. The work has been dominated by research in Latin America, and though expanding in scope in recent years, has largely focused on site prospection (Hutson *et al.* 2007, Parnell *et al.* 2002, Middleton 2004, Middleton *et al.* 2010, Middleton and Price 1996).

The work of Misarti *et al.* (2011) represents a prime example of the utilisation of geochemical techniques to identify specific suites of chemical signatures signifying particular activity areas (*e.g.*, middens, house floors, *etc.*) without the need for excavation. Through the use of principal component analysis (PCA) elemental data are analysed to characterise and then recognise groups of elements. King also neatly sums up the point of her research, stating in a markedly positivist manner that 'the soil chemistry identified differential use of space in both neighborhoods' (2008: 1236), expressing an aim of identifying discrete activity areas rather than characterising the areas themselves that has dominated this field of research. When authors have attempted to address issues of use of space (which should not be defined as being the determination of the primary function of an area but rather how individuals moved about and engaged with a space and its features) the results have been far from satisfactory. Linderholm (2007) quite clumsily defines 'use of space' through differing distribution patterns, falling back upon the concept of functional classifications of space rather than an inhabited approach to *use* of space. Whilst a space may have been used for particular activities, what do these studies tells us beyond the identification of that activity. Is any knowledge gained as to how these activities played out?

From a less positivist viewpoint concerning the application of geochemical techniques to archaeological contexts, López Varela and Dore aptly acknowledge that

> *'the definition of an activity area is also part of the problem. Mainly, archaeologists assume that only one activity takes place at a specific location…This definition introduces a static conceptualization of the use of space. This correlation tends to oversimplify human space use, disregarding that humans move in space and time to accommodate the needs of everyday life. The use of* space is dynamic' (2010: 251-252).

Here they have quite succinctly pinpointed the primary issue with current spatial studies in archaeology. They continue to remark that 'human activities are the result of conscious learned decisions concerning the locations at which a diverse range of activities will be performed…Every time an activity takes place, individuals reproduce their social world' (López Varela and Dore 2010: 252). Whilst activities are undoubtedly spatially structured, space, architecture, places, *etc.* both afford and restrict behaviours.

> *'Chemical residues trapped in this surface represent palimpsests—traces originating from the human body, the materials involved in different type of activities, and/or natural processes. It is only logical to ask how we can correlate a chemical element to an activity (see Wilson et al. 2008), if the chemical element in a sample might be the result of many activities or natural processes' (López Varela and Dore 2010: 252).*

This case is especially true for the activities that López Varela and Dore are examining in their study which are not spatially circumscribed in the same manner as metallurgical practice. Holliday *et al.* (2010: 179) also agree that there is 'no necessary or absolute relation between any particular behavior and any particular space'. There is no doubt overlap in terms of the activities that occur within a particular metallurgical context; however, it is exceedingly difficult for the vast majority of metallurgical practices to take place in multiple contexts.

An additional complaint about traditional activity area research is the apparent lack of multi-phase analyses of sites. Instead the majority of studies compare on-site data to off-site controls rather than considering diachronic change. Further a large number of these studies utilise ethnographic parallels in defining the signatures of particular activity areas, however there is virtually a complete absence of experimental work—the research is of Hjulström (2009) is a notable exception—to further investigate these analogies.

Many of the other caveats concerned with the application of elemental analysis to the study of soils and sediments (*e.g.*, Walkington 2010, Cooper and Edmonds 2007) are not applicable in the case of metallurgical practice, which introduces significant quantities of heavy metals into the soil/sediment that are not encountered from natural events. Walkington, however, is very right to remind that 'the archaeological potential of a soil hinges on the ability to establish the relationship between soil properties and the processes which formed them' (2010: 124). The question: 'which other soil properties could have formed the properties found?' (Walkington 2010: 131), though germane, can generally be answered 'none' in the case of contexts of past metallurgical practice. Both the geochemical and geophysical signatures of these activities are both significant and enduring, yet are still rarely investigated.

Though geochemical activity area research has expanded to include elements beyond P, the study of heavy metals has commonly been restricted to considering these elements as trace components of the soil matrix detectable in levels quite close to regional or national averages (*e.g.,* Terry *et al.* 2004). However, metallurgical production, amongst the traditional archaeologically studied crafts (*e.g.*, ceramics, glass production, flint knapping, *etc.*), is particularly well suited to study due to the lasting impact heavy metals involved in production make on their immediate environs. Learning from

Mesoamerican household studies, it is apparent that geochemical analysis of soils and sediments can reveal clear differences in how spaces were utilised in the past.

In 2007, Chris Carey in his PhD thesis (2007) endeavoured to explore the potential of geochemical analytical techniques to be utilised in surveys to identify evidence of past metalworking activity. Carey's work represents one of, if not the earliest investigation of the direct applicability of geochemical analysis of soils and sediments to the study of metallurgical practices. His work, primarily located in Southwest England in the areas of Dartmoor and Exmoor, focused on determining the reliability of geochemical analysis undertaken *ex situ* via wet chemical extraction and Atomic Absorption Spectroscopy (AAS) to identify archaeological evidence of ancient metalworking. The study area was selected in large part due to the metalliferous nature of region (*i.e.*, significant presence of tin, copper, lead, and manganese) as well as its long history of exploitation of these metals (Carey 2007: 72). Carey's thesis utilised three case studies representing distinct periods and/or processes (*i.e.*, post medieval ore processing sites, a Romano-British ironworking site, and prehistoric hillslope enclosures) to investigate geochemical survey as a method of site prospection. The case study sites were surveyed using a range of resolutions from 5x5m to 1x1m and samples were collected utilising either auger or trowel and taken at multiple depths from 0.2 to 0.75m. The samples from the surveys were processed in the laboratory and the results from AAS were plotted to identify anomalies. These anomalies were then investigated further in the field via gradiometer survey and excavation. The results of these attempts at ground-truthing were not surprisingly mixed—for some of the sites there was no discernible relationship detected between geochemical anomalies and evidence of past metalworking. However for the majority of sites investigated there was a discernible though 'imprecisely understood' relationship between the geochemical anomalies detected during survey and excavated metallurgical features (Carey 2007: 170). This positive relation observed between buried metallurgical features and debris and increased geochemical loading in overlying soils and sediments is critical.

Carey appears to come from a chemical or geoarchaeological background and is well versed in issues of pedogenesis and the behaviour of particular elements within the soil profile. His knowledge of metallurgical practices is however more basic and belies a lack of understanding of the specifics of iron smelting and the bodily practices involved therein. His work succeeds at demonstrating a detectable correlation between past metalworking activities and concentrations of heavy metals in the soils and sediments surrounding the evidence of these activities. When he does make brief forays into plotting out areas of metalworking activity based upon concentrations of detected elements, these efforts are theoretically under-informed and do little to add to his overall stellar research. However, where Carey excels is in pointing out that there is no one-to-one relationship between past activities and their detection thereof utilising geochemical techniques. 'There are no threshold concentrations of elements to identify a particular metalworking process. For example, Xmg/Kg of Fe at location Y does not necessarily indicate an ironworking process' (Carey 2007: 36). Geochemical evidence must always be used contextually with other forms of evidence either geophysical or artefactual to produce a fuller picture of past events.

More recently, Carey and others (Carey *et al.* 2014) have expanded upon the potential of geochemical survey for understanding past metallurgical activity. An experimental roundhouse at Trewortha Farm, Bodmin Moor, Cornwall that has long been the site of metalworking (*i.e.*, pewter and copper-alloy casting) undertaken by an experienced metal smith was analysed geochemically to investigate the relationship between known actions and measurable geochemical loadings. The interior and exterior of the roundhouse were sampled along a continuous 1x1m grid for *ex situ* ICP-MS analysis. The ICP-MS results produced were plotted as interpolated plans of the roundhouse interior that demonstrated good correlations with the informant's (*i.e.*, the smith's) recollections of his metalworking activities within the structure. Carey and his colleagues have quite successfully demonstrated the potential of geochemical analysis to identify areas of metalworking activity in the both the near and more distant past. What is less convincing is his work on use of space beyond the traditional identification of 'activity areas' that is commonplace within the aforementioned studies. The singular reliance on geochemical analytical techniques presented by Carey is perhaps best suited for prospection but much less so for the spatial characterisation of actual production sites. Carey does laud the technique for its ability to be used during the course of excavation but proposes that 'sampling needs to be targeted and hypothesis driven to eliminate massive sample numbers across large excavation areas' (Carey *et al.* 2014: 395) in order to limit the number of samples necessary to be taken. Due to Carey's reliance on *ex situ* analysis via ICP-MS these constraints are perhaps understandable, yet are easily overcome through the application of pXRF analysis which allows for more extensive sampling, blind to any preconceived hypotheses concerning the manner in which a space or even site was utilised. Further the results of our experimental campaigns will bear out the important point that only through extensive sampling can one hope to uncover the full range of signatures of practices both intentional and accidental that are preserved in the soil (*e.g.*, see Chapter 6 and Doonan 2013, Dungworth 2013).

In direct relation to the aims of this thesis Carey (Carey *et al.* 2014) has been apt to discuss the caveats of utilising experimental studies of geochemical loading to approximate archaeologically detectable metalworking sites. He does discuss some of the pedological conditions that are either more or less hospitable to heavy metal residues remaining within sediments. However it is the belief of the author that this is an issue that warrants extensive experimental consideration involving a future longitudinal study of experimental metallurgical sites. Multiple sites with highly variable soil conditions should be selected to be the locus of considerable metalworking activities over a period of perhaps six months, at which time all sites would be abandoned. Geochemical survey of all sites prior to the commencement of metallurgical activities and immediately following their cessation would be undertaken utilising portable XRF. For a period of at least five years sites would be revisited every six months to re-analyse sediments. By plotting the results of these continued analyses of the sites, we can begin to better understand the behaviour of heavy metals in the soils and sediments. In particular, potentially being able to identify the pedological conditions which are most likely to preserve metallurgical signatures.

There is a great deal of the hesitancy involved in applying geochemical techniques to past production contexts, rooted in the incredible time and monetary costs associated with wet chemical assays or ICP analysis. Further, the excessively protracted post-excavation process largely prevents the results of such analyses from ever being applied to excavation strategies. Sampling and analysing *in situ* with portable XRF allows for much higher resolution than is currently seen in geochemical surveys (*e.g.*, sampling resolution often ranges between 3x3m and 10x10m). Ideally survey sampling strategy should have a resolution of 1x1m as this measure is representative of the spacing that can capture movement of the human body. Lower resolutions (*i.e.*, >1x1m) can reveal patterning but are perhaps not as sensitive to capturing specific bodily practice.

To date most geochemical studies of soils/sediments have been undertaken using Inductively Coupled Plasma spectrometry (ICP) or wet chemical assays. Numerous studies have now compared the results of ICP and XRF analyses of soils and have demonstrated good consistency (Taylor *et al.* 2004, Carr *et al.* 2008, Pyle *et al.* 1995). Unsurprisingly ICP remains in some respects a more sensitive technique, with limits of detection below those of the XRF for many elements, but predominantly for those that have greater application in the study of ceramics and glass. XRF exhibits noticeably higher limits of detection yet the elements of interest in this study of metalworking areas (*i.e.*, K, Ca, Ti, Mn, Fe, Cu, Zn, Rb, Sr, Zr, Sn, and Pb, which are predominantly transition metals) are readily detectable at sufficiently low limits of detection to resolve spatial differences. Further, recent advances in technology that have produced the handheld portable XRF analyser (HHpXRF) have allowed geochemical analysis to move from laboratory based assessment to field based prospection, with results still being to some extent comparable to those of laboratory based XRF analysers (Frahm 2014).

The key benefit of HHpXRF is that it operates *in situ* to generate a bulk composition, although it is a surface, requiring no sample preparation (Frahm and Doonan 2013, Liritzis and Zacharias 2011). ICP and other methods (*e.g.*, varying extraction methods to determine inorganic vs. organic phosphate fractions), typically utilised for measuring elemental concentrations in soils, suffer from operating as wet chemical techniques that require the isolation of particular components/fractions of the soil prior to measurement. The prime case is phosphorous, which is measured in numerous manners and produces different resultant concentrations based on the particular speciation being measured (Holliday and Gartner 2007). One often has to carefully select a wet chemical technique to properly measure phosphorous content, yet XRF can measure all phosphorous present in a sample irrespective of its state and/or how it is bound within the soil. However, XRF does still provide less specific information in that it cannot elucidate how the phosphorous is bound up in the soil, which is sometimes indicative of the initial source (Holliday and Gartner 2007), but for the purposes of this study the measurement of elemental phosphorous is more than adequate.

Yet another benefit to utilising HHpXRF is the ability to generate data in the field that can inform sampling strategy. With *in situ* analysis it is conceivable to conduct a low-resolution survey of a site to detect hot-spots in chemical concentrations, followed by a much higher resolution targeted survey. Typical routines for taking soil samples and their subsequent post-ex examination are rigid and preclude this sort of tailored sampling strategy. By the time anomalies are identified in the laboratory, the floor layers or sites themselves are likely to have already been excavated allowing no further analysis of areas of interest.

TIME-GEOGRAPHY

A final methodology that complements the aforementioned techniques for the characterisation of space is time-geography, which addresses both the human and macroscales through the medium of the human body. Time-geography is a methodology borrowed from geography and the social sciences, based upon the premise that in order to study individuals as they move about in the world, 'we need to understand better what it means for a location to have not only space coordinates but also time coordinates' (Hägerstrand 1970: 9-10). At the most basic level time-geography is a method for mapping the movements of individuals in time and space in light of inherently unavoidable constraints upon humans' movements (Pred 1977, Giddens 1979, 1985). As noted by Hägerstrand (1970), the three varieties of constraints that affect how an individual occupies and moves through time and space are *capability*, *coupling*, and *authority* constraints:

> 'capability constraints *circumscribe activity participation by demanding that large chunks of time be allocated to physiological necessities (sleeping, eating, and personal care) and by limiting the distance an individual can cover within a given time-span in accord with the transportation technology available';*
>
> 'coupling constraints *pinpoint where, when, and for how long the individual must join other individuals (or objects) in order to form production, consumption, social, and miscellaneous activity bundles'; and*
>
> 'authority constraints *subsume those general rules, laws, economic barriers, and power relationships which determine who does or does not have access to specific domains at specific times to do specific things' (Pred 1977: 208).*

Authority constraints which are the product of social systems are difficult to take into account within the experimental 'vacuum' and subsequently were not considered in relation to the metallurgical experiments conducted as part of this study. However, the two remaining constraints of capability and coupling are easily considered and readily evident through experimental practice. Giddens (1985) was rightly critical of Hägerstrand's choice of the term 'constraints', acknowledging that these same factors could be seen to afford certain opportunities for individuals and should not be viewed in such a restrictive or limiting fashion. Whilst admiring Hägerstrand for attempting to integrate time into human geography, Giddens is sceptical of Hägerstrand's uncritical usage of the concept of place in his discussions of time-geography:

> *'The term 'place' cannot be used in social theory simply to designate 'point in space' any more than we can speak of points in time as a succession of 'nows'.*

> *What this means is that the concept of presence – rather, of the mutuality of presence and absence – has to be explicated in terms of its spatiality as well as its temporality' (Giddens 1985: 271).*

The concept of place as discussed in an earlier chapter is rooted in the actions of the agents within a particular space and time and is never independent of those actions and agents that bring it into being. Remaining cognisant of Giddens' criticisms of time-geography as a technique, it is still possible to utilise this method to better understand how experimenters approached the arena of production and ultimately made place manifest.

The technique of time-geography is deceptively simple. Based upon the novel idea that individuals and thus their actions have both space *and* time coordinates, time-geography aims to map the actions of individuals over space and time. At the basest level, time-geography can be utilised to record an individuals' day as s/he moves between different locations (*e.g.*, home, work, stores, *etc.*) to perform different routine actions as well as the means by which the individual travels between various time/space coordinates (Pred 1977, 1981). At a grander scale, the technique is commonly used by sociologists alongside urban planners to study the manner in which large populations move about cities and regions (Miller 2004, Neutens *et al.* 2010). The time scales analysed range from days to entire lifetimes, whilst the spatial dimension often ranges from small neighbourhoods to entire cities and metropolitan areas.

Challenging to use in most archaeological contexts due to the lack of visibility of past individuals, time-geography has been predominantly used in the contemporary study of place and movement, especially productivity analysis, to scrutinise how effectively time and space are used (Raubal *et al.* 2004, Michelson 1987). Here we are interested in space and the signatures of practice, and through experimental practice we are afforded the opportunity to examine the actions that produce specific signatures. A better understanding of these processes can inform our study and analysis of the spatial characteristics of routine metallurgical practice. Experimental undertakings allow us to consider the capability constraints of individuals (*e.g.*, heat resistance and physical exertion) as well as the coupling constraints (chiefly, space) of an arena of practice.

SUMMARY

There are numerous scales at which the characterisation of space is possible, but they are often disconnected. This disconnect is the product of both the techniques in use and the disciplinary divides amongst those who utilise them. There is a further temporal disjunction apparent within these strategies for characterising space, with landscape survey preceding excavation and post-ex evaluation of finds and soil samples taking place months, or even years, after a site has been closed. This time lag between excavation and the evaluation of artefacts and samples means that the results of these analyses cannot be used to inform excavation strategies, ultimately minimising a great detail of the actual import of studying small finds and soils (Andrews *et al.* 2000). There is a clear need to develop a framework which seeks to integrate these diverse scales of analysis, in some respects to bring them together in space and time. The use of HHpXRF is seen as a potential means of bridging this scalar divide in the field. Its ability to rapidly characterise space *in situ* has the capacity to direct field investigations in a more nuanced manner allowing for the recognition of particular activity areas at the time of excavation (Frahm 2014).

With a multi-scalar approach to excavations, it should be almost natural that a narrative can be woven amongst these different levels of analysis, yet this too often fails to happen. A top-down or even a bottom-up approach to characterising space often fails to convincingly weave together a cohesive whole for these differing scales. Instead we need to look to a unifying central concept around which to craft our narrative. In locating our analysis in the midst of our continuum of scale (Table 5.1) our analytical focus begins at the centre with the human scale and by necessity turns to understand practice through the vehicle of human agency. It is at the scale of the human body from which we can begin to understand practice in space both at the macro- and micro-scale (Tuan 1977). Our methods operate at all scales from the perspective of landscape down to the atoms in the soil of specific contexts, yet at all times they are recording the actions of humans in the past. By recognising what these data represent we can achieve a human-centred multi-scalar perspective, allowing us to move to writing histories which make use of the full range of archaeological evidence and reveal as a consequence a fuller insight in to the human condition.

Chapter 6. Experimental Methods & Results

INTRODUCTION

The presence of large scale experimental undertakings in countries such as England (Butser Ancient Farm) and Denmark (Lejre Experimental Centre) where prehistoric dwellings, amongst other endeavours, have been reconstructed, has helped popularise the practice of experimental archaeology (Reynolds 1979, Rasmussen 2007, Nancke-Krogh 1990). While such reconstructions are highly informative, and visible, they rarely form the core of academic experimental work. Experimental archaeology is one of many heuristic devices used to investigate ancient technologies and has become an increasingly popular aspect of research programmes (Jeffra 2008, Schiffer *et al.* 1994, Crew 1991, Friede and Steel 1977, Merkel 1982, Wynne and Tylecote 1958, Papadopoulos *et al.* 1998, Nerantzis 2012), often undertaken in cooperation with living practitioners, of 'traditional' crafts (Evely and Morrison 2010, Akerman 2007).

Reynolds, one of the earliest and strongest proponents of experimental archaeology, was keen to dismiss the role of the individual in an experiment,

> *'no experiment can be designed to enhance our understanding of human motive or emotion in the recent or remote past' (1999: 388).*

This idea has reinforced the belief that experimental archaeology is only scientific when such practices are devoid of human subjects. By equating the subjective realm of *emotions* with the inclusion of human subjects, Reynolds leads us to believe that there is no role for the experimental practitioner other than that of technical operator.

Reynolds did little to explore the central paradox which exists at the core of experimental archaeology, especially when used for the study of craft. At the very heart of craft production is the *skilled knowledgeable agent*, versed in techniques of the body that define craft practice. To remove such central figures in experimental studies is to remove the very object of study that archaeologists should seek to reveal. The experimental crafter is inextricably bound in the experimental performance and should be accepted as an integral component. Rather than debate the degree of objectivity we should seek to understand what we can from such experiences both when we act as the central figure and when we observe. The skilled individual is an actively engaged individual caught up in the act of craft production; it is very much a performative role (Ingold 1990). While much has been achieved in the last two decades concerning choice, technique, and practice within technology studies, we have done little to explore how these aspects of craft connect with space. This connection is important as such experiments can begin to provide insights that allow us to work more effectively with concepts of space in archaeological contexts that concern craft production.

Such a proposal is not entirely novel, as recent overviews have tended to highlight similar concerns. For instance Outram (2008), in a recent review of experimental practice, sees the field divided between the contrasting, yet ultimately complementary purviews of laboratory-based experiment and actualistic scenario-based endeavours. While there is certain value in purely laboratory-based experimentation, it is only through accommodating the role of the experimenter in craft experiments that we can hope to use experiment to provide insight into practice and that must certainly be grounded in analyses of space.

The experimental campaigns undertaken here sought not to replicate or recreate past practice in any specific manner but rather act as a series of endeavours where the relationship between practice and the formation of archaeological contexts could be examined. This view of experimentation might seem *blasé* but whilst experimentalists might enthusiastically pursue process accuracy, they should be cautious of confusing their actions for adequate representations of any archaeological meaningful *chaîne opératoire* (Doonan 2013, Dungworth 2013). The concept of practice goes beyond techniques and sequences of activity (Bourdieu 1977, Edmonds 1990a, 1990b). The experimenter can never reconstruct an ancient technology in its fullness (Schiffer and Skibo 1987). Experimentation *constructs* rather than *re*constructs practice but this by no means lessens the import of experimental endeavours. Experimental archaeology seeks to construct new frames of reference from which to approach the archaeological record. Experimentation therefore allows the experimenter to recognise the embodiedness inherent in our Being-in-the-World, that is, to discover elements of a common ground between past practice and present engagement (Jackson 1989: 135).

Metalworking activities are particularly fruitful for study as they are in essence transformative pyrotechnological processes, which tend to chemically and physically ‘imprint’ open contexts in a manner that is more detectable and less ambiguous than other human activities (Oonk *et al.* 2009c, Oonk *et al.* 2009b, Jouttijärvi 2009, Haslam and Tibbett 2004, Aston *et al.* 1998). Though experimental reconstructions of pyrotechnical equipment and processes can aid in elucidating preferred operating conditions and constraints upon technical performance, seldom have these experiments been used to interrogate practitioners' engagement with the sort of features recovered archaeologically.

Ideally, analysis of the individuals' bodily movement and engagement during an experiment can provide a complementary perspective to the more familiar work involving the analysis of geophysical and geochemical signatures of particular activities. In other words, whilst choice in material selection and technical practice has been well documented, there exists great potential to develop our spatial understandings of these actions through the identification of signatures of practice.

GENERAL METHODS

In order to investigate practice—as potentially preserved in the soil—geochemical and geophysical techniques (discussed in Chapter 5) were utilised to examine the impact of a number of experimental metallurgical activities upon their immediate environs. The experimental programme was field-based and often involved volunteers from a number of organisations. A variety of furnace and hearth structures were employed in the experimental campaigns and included experiments that addressed the production and working of iron and copper (Table 6.1). Most furnaces were based upon Iron Age approximations (Fox 1954b, Cleere 1971, Tylecote 1986, Tylecote *et al.* 1971).

Experimental Campaign	Date	Location	Details
A. Ferrous metallurgy			
I. Ferrous smelting	Autumn 2011	Endcliffe Park	Slag-tapping shaft furnace & bowl furnace
II. Ferrous smithing	Autumn 2011	Trippet Wood	Primary bloom smithing & secondary smithing
III. Ferrous smelting & smithing	Autumn 2012	Ecclesall Woods	Slag-tapping shaft furnace smelt & primary bloom smithing
B. Copper-base metallurgy			
IV. Copper smelting	Summer 2012	Manor Farm	Extended bowl hearth/furnace
V. Copper smelting & casting	Autumn 2012	Ecclesall Woods	Bowl hearth
C. High-temperature non-metallurgical activity			
VI. Cooking fire	Autumn 2012	Ecclesall Woods	Unenclosed fire

Table 6.1 Summary table of experimental campaigns conducted and considered within this study.

Geochemical and Geophysical Analysis

The experimental activities were all performed within defined areas that were sampled on a grid system at resolutions ranging from 0.25x0.25m to 2x2m for areas of 2x2m up to 10x10m. Prior to experiments being undertaken, the localities were all subjected to initial geochemical and geophysical survey so as to establish initial soil conditions. These readings were repeated over the course of the experiment most commonly on the day following experimental activities prior to commencing a new round of experimentation, and in some instances followed up for some time after the termination of experimental activities. Where possible, measurements were taken *in situ* via HHpXRF and magnetic susceptibility probe. In some case, soil samples were collected so that measurements could be taken *ex situ* in the laboratory. All pXRF readings are presented as parts per million (ppm). Magnetic susceptibility readings taken *ex situ* are measures of low-frequency mass-specific susceptibility χ_{LF} (*i.e.*, 10^{-8} m^3 kg^{-1}). When *ex situ* readings were taken on samples of less than 10 cm^3 the χ_{LF} was corrected for volume.

Time-Geography Analysis

For the Copper Smelting experiment undertaken at Manor Farm (Table 6.1) time-geography techniques were employed to complement the geochemical and geophysical data and to better understand the use of space as well as the segregation of particular activities within a metallurgical endeavour. Data were collected during the course of the experiment utilising time-slice photography taken by a Canon PowerShot A560 camera mounted on a pole three metres above the site at the bottom centre of the area. The camera was programmed to take pictures every 30 seconds, which were later imported into Windows Movie Maker where they were combined to create separate films for each day of experimentation in order to analyse the movements of the experimenters in time and space.

DATA COLLECTION

A variety of methods were used throughout in terms of experimental design as well as sampling strategy; for the purposes of these experiments all sampling involved grid or lattice sample designs. Grids for all experimental sites were laid out over areas ranging from 10x10m to 2x2m, at resolutions of 0.25x0.25m up to 2x2m. Samples were taken from within the squares created by the grid, following systematic random sampling methods (Richardson and Gajewski 2003, Orton 2000), rather than at specific points of intersection along the grid or at the centre point of a unit as is utilised in a basic systematic strategy (Figure 6.1). This strategy of sample collection was adopted primarily to avoid overly clearing one section of the ground and masking the effects of experimental activities on the topsoil.

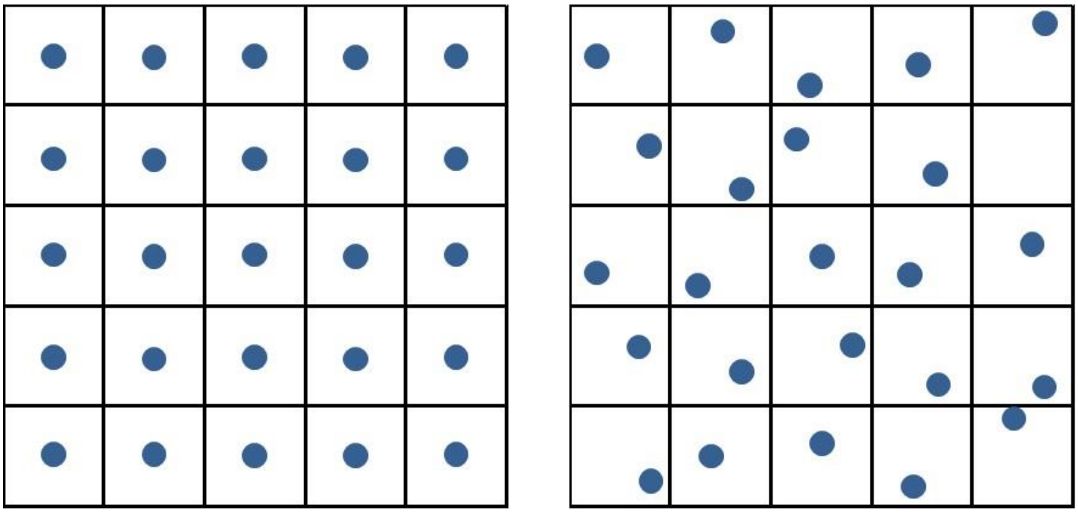


Figure 6.1 Examples of sampling grid designs utilising (*left*) basic systematic sampling and (*right*) systematic random sampling.

Systematic random sampling was selected as the most effective means of characterising the experimental spaces, namely because it is the method commonly (though not exclusively) utilised in the archaeological excavations (Parker Pearson *et al.* 2004: 71-73, Wells and Urban 2002, Entwistle *et al.* 2007, Oonk *et al.* 2009c, Terry *et al.* 2004, López Varela and Dore 2010) that were also being investigated and that it limited bias by ignoring visible features in the areas prior to sample collection. Whilst systematic sampling may be the method most adept at characterising a space, it is seldom the most efficient, hence the preponderance of other methods in geospatial studies (*e.g.*, semi-systematic sampling: Fernández *et al.* 2002, Oonk *et al.* 2009b, Wells *et al.* 2000; non-random sampling: Dore and López Varela 2010). When soils are geochemically analysed using wet chemical techniques or ICP-MS, high-resolution sampling strategies are overly time consuming and grossly expensive. To deal with the issue of analytical burden, Haslam and Tibbett (2004), as well as others (*e.g.*, Wells 2010, Dore and López Varela 2010), have investigated a variety of strategies to maximise the clarity of spatial characterisation whilst simultaneously reducing the overall number of samples needed to do so. For this study, there was one main advantage over traditional soil studies—the use of *in situ* portable X-ray fluorescence (pXRF) to analyse soils. Typical geochemical investigation of soils involves taking samples in the field using individually labelled bags which are then processed back in the laboratory over a period of months by a post-ex specialist in tandem with a chemist. This process is laborious, time consuming, and expensive and due to its distance from the actual contexts of excavation rarely (if ever) allows for geochemical results to inform strategies in the field in a reflexive manner. The ability to characterise soil chemistry in the field in the midst of excavation can lead to ever evolving sampling strategies that adjust sampling resolution to most efficiently characterise entire sites as well as areas of particular interest. Whether utilised *in situ* or *ex situ*, the speed at which pXRF is able to characterise soil samples (*i.e.*, at minimum 35 seconds to make elemental determinations) allows for sampling strategies with higher resolution.

One of the major issues highlighted in geochemical studies of archaeological sites has been the determination of off-site controls from which to measure variation against (*e.g.*, Entwistle *et al.* 2000, Haslam and Tibbett 2004, Fernández *et al.* 2002, Hutson *et al.* 2007, Terry *et al.* 2004). Within the context of prospection studies this is problematic as what constitutes an 'off-site' control is impossible to determine as the limit of a site can never be established with certainty. For this study such controls have never been sought. The methods involved herein are not focused on site prospection but rather on examining how particular soil contexts change in light of specific activities performed upon them.

EXPERIMENTAL CAMPAIGN A. FERROUS METALLURGY

Experiment I. Ferrous Smelting

Experimental Design

The first experiment of the ferrous metallurgical campaign involved the production of iron via direct reduction (Tylecote 1986: 128) utilising both a bowl furnace and a slag-tapping shaft furnace—both of which having Iron Age parallels—used in close proximity (Fox 1954b, Cleere 1976, 1977).

Experiment I was conducted over a period of four consecutive days in October 2011. A 10x10m area within Endcliffe Park, Sheffield was cleared of branches and other large items of natural debris (leaf litter and other small debris remained untouched, yet naturally through the course of the experiment this material was redistributed). Within this area a shaft furnace and bowl furnace (Figure 6.2) were constructed using local clay mixed with sand and straw temper. Iron ore was piled within the areas in readiness for crushing. As metallurgical activities would occur at the site over multiple days, the experiment presented an opportunity to witness how geochemical and geophysical changes manifested themselves in the surrounding soil when a bowl and shaft furnace were used for an extended period utilising traditional bellows. Geochemical data were gathered with a Niton XL3T used in hand and in Soil Mode with a 35 second analysis time (Niton XL3T-HH-Soil-35) while magnetic susceptibility data were collected using a Bartington MS2 Magnetic Susceptibility Meter, *in situ* with a Bartington MS2D Surface Scanning Probe or in the laboratory with a Bartington MS2B Dual Frequency Sensor.

Prior to commencement of metallurgical activities, the 10x10m site was surveyed at 2m intervals. These data were recorded as Day0 for the site; data were then taken following all smelting events on Day3, Day4, and Day5. On Day6, both furnaces were dismantled and ore and slag were removed to restore the area to as close to natural as requested by the landowner. The site was then revisited 13 days later (*i.e.*, Day18) in order to conduct further geochemical and geophysical survey. At this time data from the site had been preliminarily evaluated, suggesting that a higher resolution survey would better discriminate patterning within the experimental area. Thus for the final geochemical and geophysical survey, data were collected along 1m transects at 1m intervals.

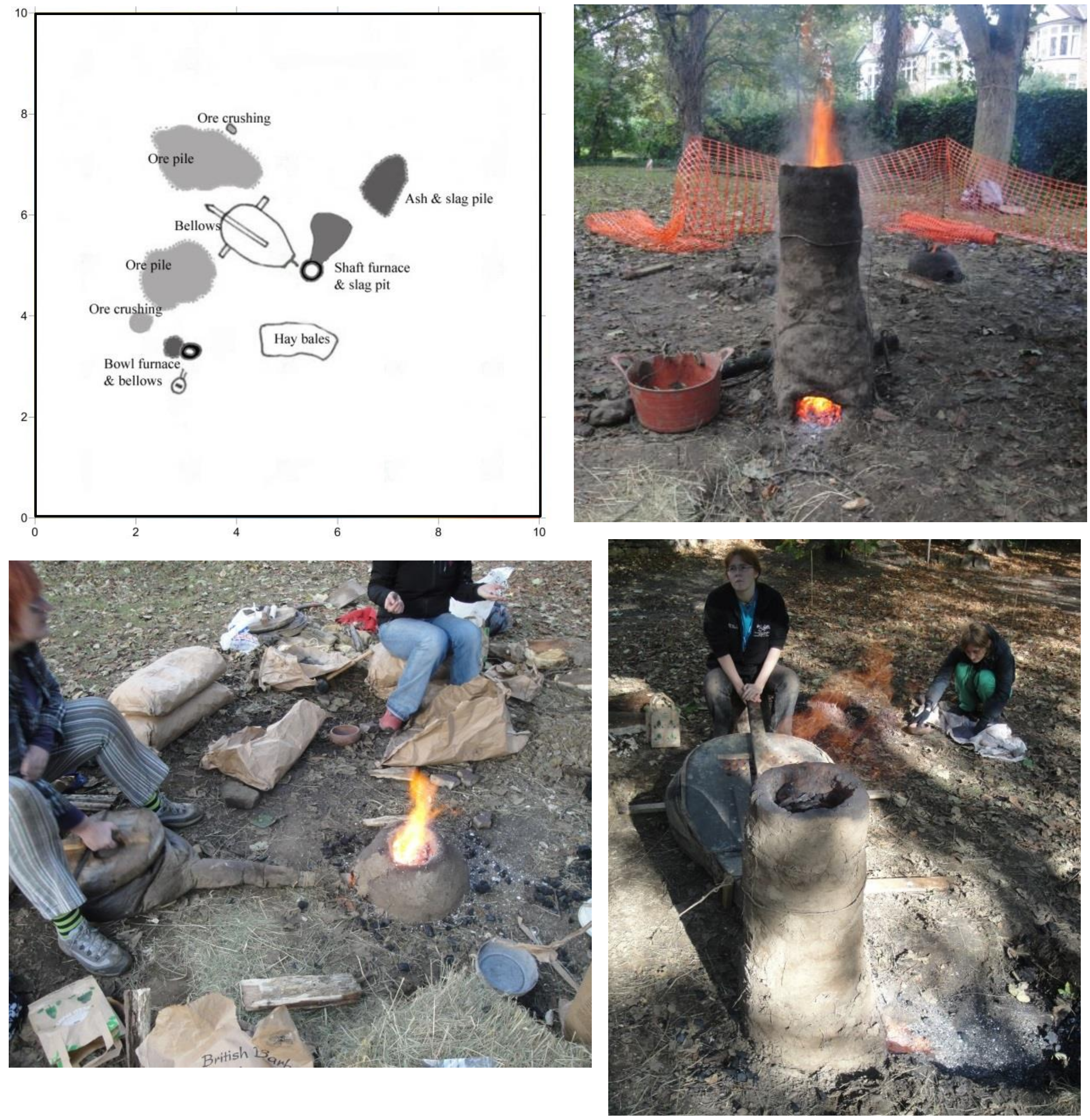


Figure 6.2 ***Clockwise from upper left:*** **Plan of Experiment I site Endcliffe Park, Sheffield, scale in metres; image of experimental site with shaft furnace in foreground and bowl furnace in the background, both being preheated prior to smelts (photograph courtesy of B. Comeau); image of bowl hearth being operated using a set of single chambered cylindrical bag bellows, individual in right background is crushing ore for the charge (photograph courtesy of B. Comeau); and image of shaft furnace being operated with a set of large, single chambered hinged bellows, whilst another individual to the right crushes ore (photograph courtesy of B. Comeau).**

On each of the four days, the shaft furnace was preheated using wood and charcoal for at least one hour, prior to being completely filled with charcoal (Figure 6.2). At this point, a mixture of charcoal and ore (*i.e.*, the charge) was added to the furnace in a predetermined ratio of ore to charcoal as the charcoal was consumed by the fire. The smelts predominantly utilised a high-grade pelletised ore, with a single trial combining it with a naturally occurring ore from Dragonby mines with a markedly lower iron oxide content (approximately 25% Fe by weight) (Harrison *et al.* 2005). The furnace was charged for approximately three to five hours at which time only charcoal was added for a period of time as the charge was allowed to fall in the furnace and reach the reaction zone near the tuyère. When it was determined that the charge had had significant time to react in the furnace, the front of the shaft was opened, and attempts were made to tap the furnace. The furnace was only minimally successful in producing tap slag, though this is largely due to the high iron oxide content (approximately 65% Fe by weight) (Meyer 1980) of the commercial pelletised ore which was utilised predominantly for the experiment. Upon opening the furnace, any remaining charcoal and charge are raked out and the bloom is removed (often forcibly). The first two experiments successfully produced iron blooms, whilst the third experiment which utilised two types of ore and a higher charcoal to ore ratio, only produced slag.

Shaft Furnace							
Day	Smelt	Ore/Charcoal ratio (kg)	Total Ore (kg)	Total Charcoal (kg)	Ore type	Product	Notes
2	1	1:1.5	6.5	20	pellet	small bloom	
3	2	1:2	3.5	14	pellet	bloom	tuyère repositioned
4	3	1:3 or 1:4	5	35	pellet & Dragonby	slag	
5	4	1:2	5	20	pellet	bloom	

Bowl Furnace							
Day	Smelt	Ore/Charcoal ratio (kg)	Total Ore (kg)	Total Charcoal (kg)	Ore type	Product	Notes
2	1	1:3.5	1.5	5.5	pellet	conglomerate	
3	2	1:2.8	1.5	4.3	pellet	burnt ore	Catalan forge method

Table 6.2 Shaft and bowl Furnace smelts and products from Experiment I Endcliffe Park, Sheffield.

On Day2 and Day3, the bowl furnace was charged for smelts, after being preheated using wood and charcoal (Figure 6.2). On the first day, the bowl was charged in a manner similar to a shaft furnace where ore and charcoal are introduced in layers to the furnace at a ratio of approximately 3.5kg charcoal to 1kg of pellet ore. This smelt produced a conglomerate that was largely slag but did exhibit some small areas of metallic iron. The second smelt followed the ‘Catalan forge’ method of charging (Rehder 2000) in which all ore is introduced at once along the side of the furnace directly opposite the tuyère. For this smelt, the furnace was charged using a ratio of 2.8kg charcoal to 1kg ore but was entirely unsuccessful in producing a bloom or conglomerate of any sort (Lucas *et al.* 2012).

Results

Handheld pXRF was used to determine Zn, Pb, Zr, Rb, Fe, and Mn at sampling locations. Measurements taken on Day0 (*i.e.*, experimental baseline) for the experimental site when compared to all other days revealed reductions in elemental concentrations of virtually all elements as well as magnetic susceptibility (**Error! eference source not found.** and Appendix A). The process of sampling necessitated the light trowelling of topsoil to ensure that no foreign objects perforated the pXRF window. This procedure may account for the differences between the initial day and those following. When comparing the baseline readings and those taken on subsequent days, not all measures of geochemical and geophysical variation are uniformly useful for illustrating the activities that took place therein. However, Fe, Mn, and magnetic susceptibility appeared to be sensitive to the experimental activities carried out within the site and are discussed further below.

Manganese readings proved most adept at revealing the location of one of the ore piles within the experimental site (**Error! Reference source not found.**). For Day4 there is a ery prominent anomaly (5080 ppm, Appendix A) correlated with the position of one of the ore piles, specifically the Dragonby ore, which is not overly rich in Fe as noted previously. On the following day, there is another point of elevated Mn in the same position on site, but at a level (1140ppm, Appendix A) much closer to the upper limit of the baseline data. Despite markedly high Mn concentrations recorded on Day4, there was little lasting impact on the soil from the presence of the ore after the site was cleared on Day6. When readings were taken again on Day18, the location of the Dragonby ore pile is no longer discernible. In contrast to previous days, the points of elevated Mn are well within the baseline values for the site recorded on Day0 (*i.e.*, 715-1016ppm, Appendix A).

Not surprisingly Fe is one of the elements most reflective of the metallurgical activities that occurred within the experimental site. The initial survey of the site revealed higher levels in the lower left quadrant (**Error! Reference source not found.**). This area of ncreased Fe concentration was soon masked by activities undertaken on site and for Day4 and Day5 the observable anomalies are well-correlated with the location of the ore piles, similar to those observed for Mn. On the final day of survey, there is a cluster of anomalies in the lower left quadrant of the site in the area between the bowl furnace and the ore piles. The previously mentioned lack of visibility of the cleared ore piles on the final day in both Fe and Mn concentrations, suggests that this cluster of Fe anomalies in the area of the bowl furnace is the product of smelting slag and unreacted ore left within the furnace structure rather than any lasting impact of the crushing or stockpiling of ore. It is perhaps surprising that the location of the shaft furnace is never revealed through Fe concentrations as at least 20kg of iron ore was added to the site through the process of smelting over the course of the four days, whilst only 3kg of ore was charged in the bowl furnace. Interestingly, the location of increased Fe concentration in association with the bowl furnace is the only anomaly to show a correlation with the magnetic susceptibility readings across all days for the site, which lends further support to the notion that the source of the increased Fe was from furnace material.

The geochemical readings from the site have been of varied utility in illuminating the metallurgical activities that occurred over the course of experiment. Notably, the majority of elements detected by pXRF were not were useful for indicating the presence of either furnace (Figure 6.2). However, on Day18 the Fe anomalies noted in the lower left quadrant of the site are located between the bowl furnace and the ore stockpiles and could be representative of either's influence on the soil. Geochemical analysis was most successful at highlighting the position of ore stockpiles as well as the location of ash and other metallurgical debris removed from the shaft furnace. Shifting patterns of diminished elemental concentrations within the site also served to emphasise the areas which were subject to greater foot traffic and clearance over the course of the experiment. Unsurprisingly, no single element, as determined by *in situ* HHpXRF performs well in providing a detailed geochemical signature of metallurgical activities undertaken for the experiment. While some Mn and Fe might hint at the storage of raw materials, these signatures seem to disperse quite rapidly.

Magnetic susceptibility provided an additional data set for the experiment. Readings were taken both *in situ* and *ex situ*, with *in situ* readings taken three times and then averaged and *ex situ* samples weighed and read three times then averaged and adjusted for density (Appendix A). Actual magnetic susceptibility readings are not entirely comparable when taken *in situ* and *ex situ*. Those measurements taken in the laboratory were from surface scrapings of the topsoil, whilst the *in situ* readings reflected the field coil's ability to penetrate 10cm into the soil to measure susceptibility (Bartington 2014). The lack of observable variation in the magnetic susceptibility values over the Day0 through Day5 is likely a combination of the *ex situ* analytical procedure in concert with the low sampling resolution of 2x2m, which was increased to 1x1m prior to taking Day18 measurements (**Error! Reference source not found.**). On the final survey day, he data reveal magnetic susceptibility enhancements that are strongly correlated with the locations of shaft furnace, slag-tapping pit, bowl furnace, and the ore pile and/or ore crushing areas as well as the metallurgical debris piles for both the shaft and bowl furnace. The ability of the magnetic susceptibility to correctly identify metallurgical debris is important as it is often the detritus of metallurgical activities rather than the architectural features that produced them that remains on a site over time.

Experiment I has shown magnetic susceptibility to be the most effective technique for delineating production signatures associated with experimental ferrous metallurgical activities undertaken in multiple furnace structures. The use of different sampling resolutions between the initial and final readings highlights the importance of survey design in determining the appropriate resolution for detecting certain activities. However, the change in resolution between the initial and final readings highlights the importance of survey design in determining the appropriate resolution for detecting certain activities.

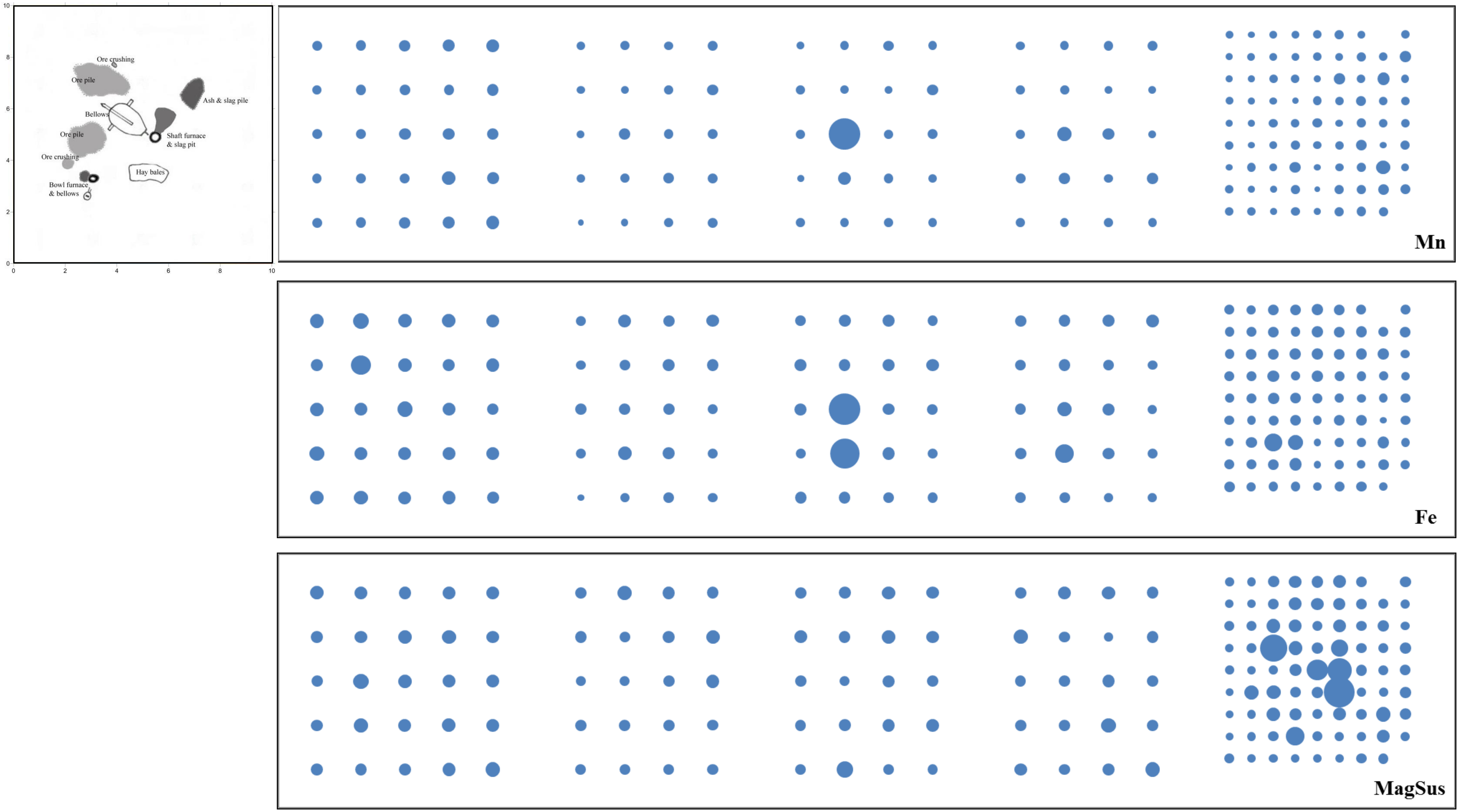


Figure 6.3 Bubble plots of Mn and Fe concentrations and magnetic susceptibility readings from Experiment I Endcliffe Park, Sheffield alongside plan of site. ***From left to right:*** **Day0, Day3, Day4, Day5, and Day18.**

Experiment II. Ferrous Smithing

Experimental Design

Ferrous smithing was performed as an adjunct to the activities of Experiment I, over the course of the same four days in October 2011. At a site in Trippet Wood, Sheffield, removed from the locus of smelting, the blooms produced in the experimental shaft furnace underwent primary (bloom smithing or refining) and secondary smithing by professional blacksmiths in two discrete locations (McDonnell 1995). Following the culmination of smithing activities the two areas were surveyed at 1x1m resolution to collect magnetic susceptibility data utilising a Bartington MS2 Magnetic Susceptibility Meter and Bartington MS2D Surface Scanning Probe. Hammerscale density was recorded by taking bulk soil samples of approximately 0.2L from both sites along the 1x1m grid, which were then dried in the laboratory (Bayley *et al.* 2001). Once dry, the samples were spread out and a magnet was used to extract the scale from the soil. The hammerscale was then counted with the aid of 10x light microscope.

Results

There were no baseline readings taken for either of the smithing sites, however, it is to be expected that there would be no prior evidence of hammerscale at either location. Both sets of magnetic susceptibility readings demonstrate anomalies that do not seem consistent with natural variation, though the anomaly for Experiment II – secondary smithing (Figure 6.5) is not clearly correlated with the location of smithing activities. The data from the primary bloom smithing demonstrates a halo effect of hammerscale being projected away from the anvil due to the percussive nature of the smithing (Jouttijärvi 2009, Dungworth and Wilkes 2009) (Figure 6.4). During primary smithing the spongey bloom is consolidated through percussive force that serves to drive out the slag that is intermixed with the iron metal. It is unsurprising that there was a greater concentration of hammerscale detected during this phase of smithing as the size of the scale would make it easier to recognise. Whilst the spread of hammerscale rings the location of the hearth and anvil, it is at the centre of those features that magnetic susceptibility is greatest. It is to be assumed that the enhancement in this locale is due to heat from the forge rather than the addition of iron oxides to the soil, as there was no hammerscale recorded for this area. The magnetic susceptibility anomaly is well-structured expanding out from the centre of the anvil revealing the spread of impact of smithing activities on the surrounding soil.

The secondary smithing data are much less structured and demonstrate a much more even spread of hammerscale with notable points of high concentration to either side of the anvil. The magnetic susceptibility data however is still informative as to the location of practice. There is a line of higher enhancement towards the right hand side of the site along with the one exceptionally high anomaly. The position of the line to the right of the anvil suggests that, if right-handed, the blacksmith stood above the position of the hearth and anvil and pounded the billet causing sparks of hammerscale to fly off towards his left and in front of him.

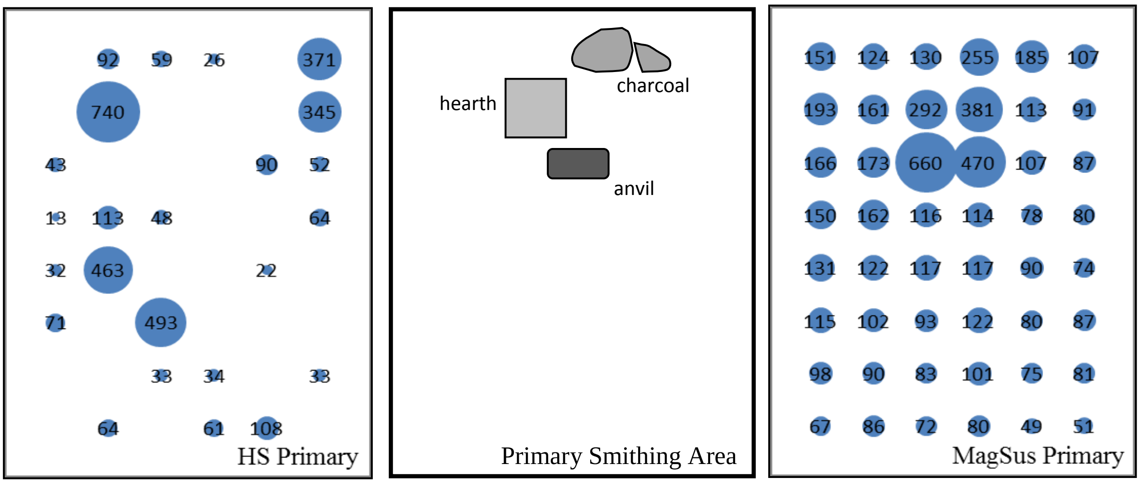


Figure 6.4 ***From left to right*****: bubble plot of hammerscale concentrations; schematic of site; and bubble plot of magnetic susceptibility readings for Experiment II - primary smithing Trippet Wood, Sheffield.**

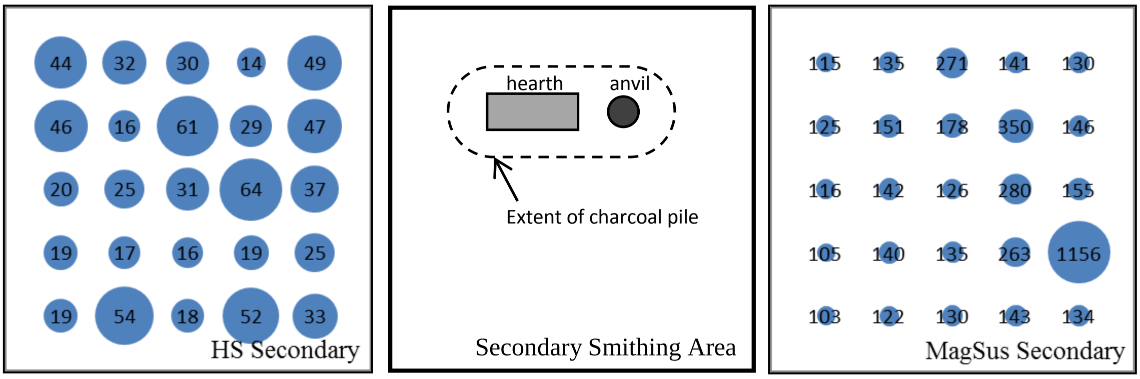


Figure 6.5 ***From left to right*****: bubble plot of hammerscale concentrations; schematic of site; and bubble plot of magnetic susceptibility readings for Experiment II – secondary smithing Trippet Wood, Sheffield.**

Experiment III. Ferrous Smelting & Smithing

Experimental Design

The second iron smelting experiment of the programme was carried out in Autumn 2012 at the J G Graves Woodland Discovery Centre, Ecclesall Woods, Sheffield, UK. As in the first experiment, a slag-tapping shaft furnace was utilised to produce iron via direct reduction smelts carried out over the course of three weeks. A 3x3m area,

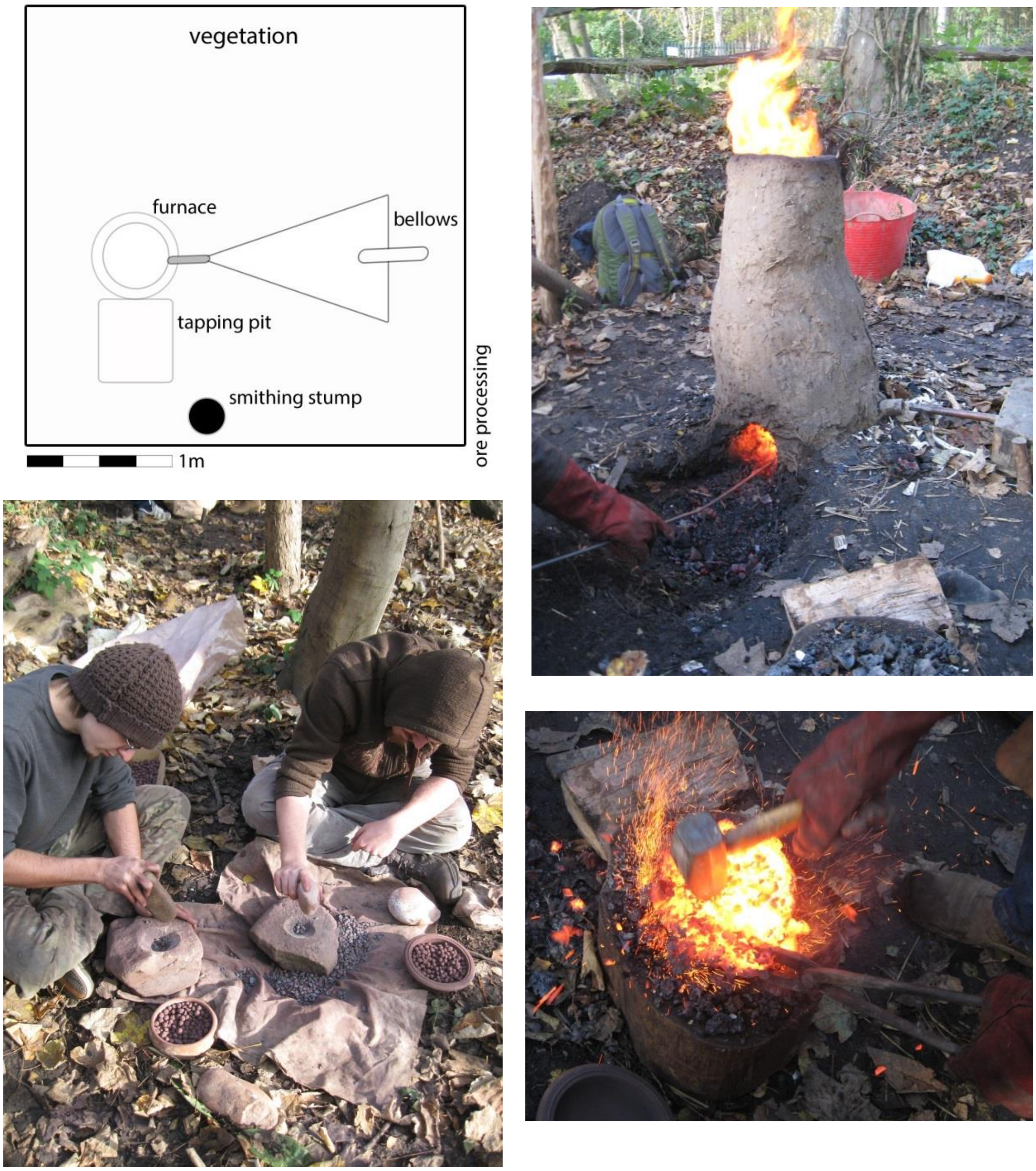


Figure 6.6 ***Clockwise from upper left:*** **Plan of Experiment III Site A, Ecclesall Woods, Sheffield (image by author); image of experimental site with shaft furnace at centre being tapped, in foreground is the stump used for smithing, and to the right is a portion of the bellows utilised for forced draught (photograph by author); image of primary bloom smithing carried out directly after removing bloom from the shaft furnace (photograph by author); and image of two students processing the pelletised ore for the iron smelt by crushing with hammerstones (photograph courtesy of J. Karjalainen).**

designated Site A, was cleared of branches and natural debris and the shaft furnace was constructed of local coal measure clay. Similarly to Experiment I, ore was crushed on site in preparation for smelting, yet the location of this activity was slightly outside of the experimental area due to space constraints.

As with Experiment I the smelts occurred over a period of time (*i.e.*, 27 October, 2 November, and 16 November) allowing the experimenters to measure changes in geochemical and geophysical measurements. Geochemical data were gathered with a Niton XL3T used as a benchtop unit with a He purge in Mining Mode with a 90 second analysis time (Niton XL3T-BT-Mining-90), while magnetic susceptibility data were collected using a Bartington MS2 Magnetic Susceptibility Meter in the laboratory with a Bartington MS2B Dual Frequency Sensor. Prior to commencement of metallurgical activities, the 3x3m site was surveyed along 0.5m transects at 0.5m intervals on 26 October. These data were recorded as 26Oct for the site; data were then taken following the first two smelting events on 9 November (9Nov) and after the final smelt on 16 November (16Nov). Due to equipment availability all samples were collected in the field to be analysed *ex situ*. Samples were processed in the laboratory, where they were dried overnight in an oven at 75 °C, ground into a fine powder, and then placed in sample pot covered with a 4μm proline window and weighed prior to pXRF and magnetic susceptibility measurements.

Results

Not all elements were above detection limits and only the following were processed and plotted: Zr, Sr, Rb, Pb, Zn, Cu, Fe, Mn, Cr, Ca, K, S, and P. Unlike Experiment I, the use of Mining Mode permitted a wider range of elements to be plotted, including P which is a common element investigated by geoarchaeologists (Bethell and Máté 1989, Craddock *et al.* 1985, Crowther 1997, Holliday and Gartner 2007, Hutson *et al.* 2009, Roos and Nolan 2012, Ullrich 2013, Weston 1995, Haslam and Tibbett 2004). As is expected, not all elements were of equal utility in elucidating the practices that took place over the course of the experiment; subsequently not all concentration plots will be included in the body of the chapter. Of the elements detected, Zr, Pb, Zn, Cu, Mn, Cr, S, and P all exhibited patterning uncorrelated to the activities that took place within the experimental site and were most likely reflective of underlying geochemical variation (see Appendix A). The readings for remaining elements of Rb, Fe, Sr, Ca, and K, as well as the magnetic susceptibility measurements, are illustrative of the arrangement of the experimental space as well as the activities that took place within it.

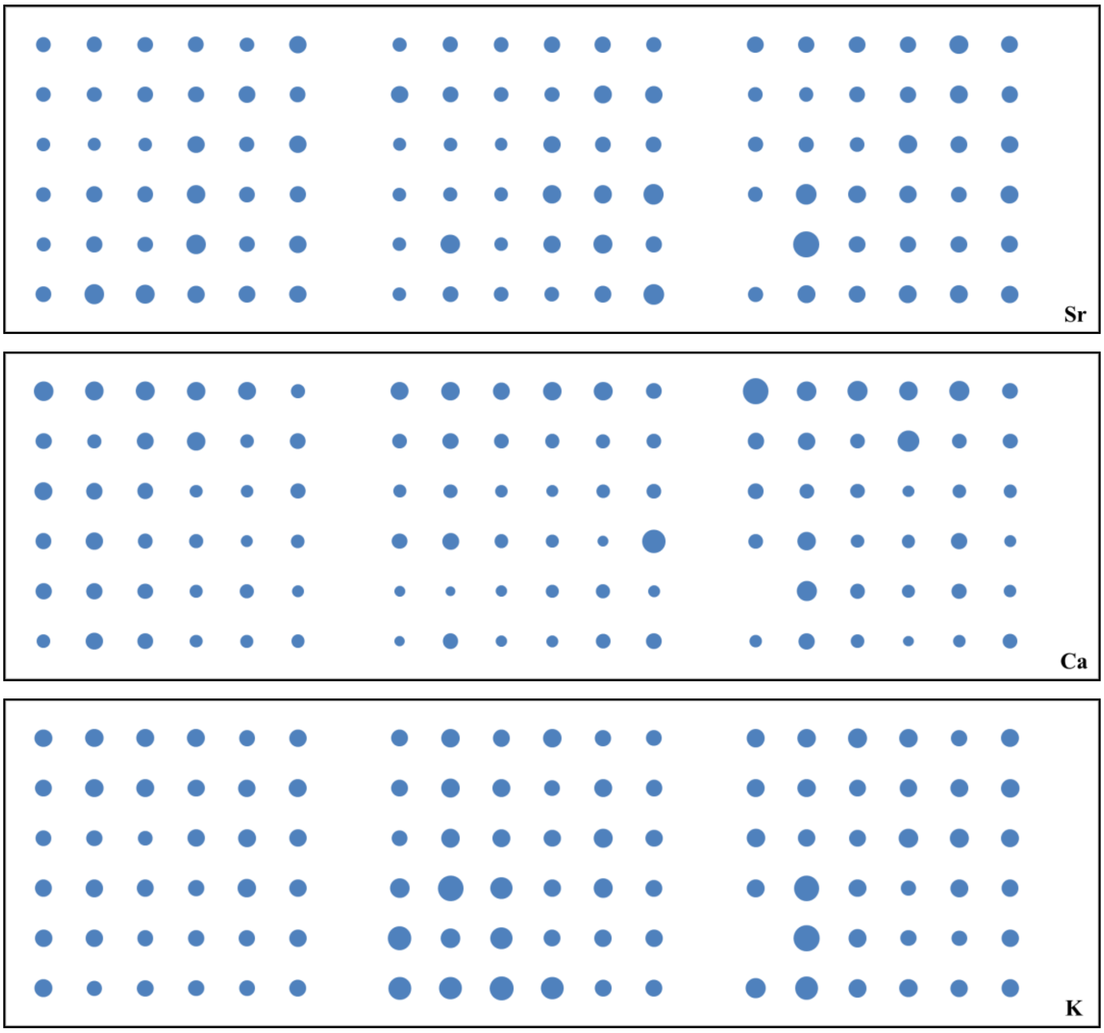
Strontium, Ca, and K exhibited similar patterns of concentration over the course of the experiment (Figure 6.7). Strontium itself demonstrated relatively stable concentrations across the area and over time, yet did present a single noticeable area of enhancement on 16NovPM in the lower left quadrant of the site. The anomaly is well-correlated with the experimental activities carried out within the site focused around the tapping of the iron smelting furnace and subsequent removal of ash and unreacted ore. Potassium readings revealed a more extensive anomaly centred upon the lower left quadrant of the experimental area, most noticeably on 9Nov and 16Nov. Lastly Ca revealed similar continuity of concentration to Sr over the two weeks, with a limited area of increased concentration detectible on 16Nov in the same location as that Sr. The correlation not only of these particular elements but also their spatial association with the location of the furnace and the slag tapping pit is unsurprising. All three elements are present in wood ash and were likely derived from the burning of wood and charcoal within the shaft furnace.

Rubidium exhibited subtle increases in concentration over the course of the experiment largely focused upon the lower left quadrant of the experimental area. The baseline levels of Rb in the soil were low in Ecclesall Woods (*i.e.*, 19-33 ppm) likely due to predominantly humic nature of the woodland substrate (Salminen *et al.* 2005: 301). The additional Rb that was demonstrated by increased concentrations was potentially derived either from geogenic sources through the coal measure clay of the furnace or via ash from the burning of wood and charcoal over the course of the experiment (Salminen *et al.* 2005: 299, Siddique 2008). Whilst the specific origins of the increased Rb are not entirely clear, the association of the Rb enhancement area with both the location of the furnace and the slag tapping pit suggests the element was contributed through the activities of the experimental smelting process (*i.e.*, the construction and/or utilisation of the furnace).

Iron, as expected, exhibited an increase in elemental concentration during the ferrous smelting and smithing experiments. However, as opposed to Sr, Ca, K, and Rb, the areas of Fe enhancement were not as spatially well-circumscribed. On 9Nov and 16Nov there is a noticeable locus of increased concentration of Fe in the area of the furnace and slag tapping pit. However, there is also a visible anomaly on 16Nov near the centre of the experimental area. This anomaly above the area occupied by the bellows is most likely the result of inadvertent discard of ore during the process of charging the furnace. Smithing of the blooms did occur at bottom centre of the area following the smelts. Yet, there are no discernible anomalies associated with this activity as the Fe concentrations for that particular region of the site remain relatively constant over the course of the experiment. It is possible that any potential impact on Fe concentrations caused by the smithing has been subsumed in the previously discussed readings that are seen to be associated with the furnace tapping pit, as the small size of the experimental area perhaps leads to less clarity in terms of teasing apart different activities and their resultant impacts on the soil. In particular the close proximity of ore charging, furnace tapping, and bloom smithing activities within the 3x3m area makes confident correlation between practice and geochemical data taken at a resolution of 0.5x0.5m challenging.

Magnetic susceptibility readings for the experimental site complement well the results of the geochemical survey. The baseline levels of magnetic susceptibility remained relatively stable across the site, with readings on 9Nov and 16Nov in the lower left quadrant convincingly demonstrating a structured anomaly associated with the furnace and slag tapping pit. To the right of the location of the tapping pit, on 16Nov is a set of anomalies that are suggestive of a 'halo' of enhancement around the location of the smithing stump (*i.e.*, the appearance of a characteristic shadow, devoid of scale where an anvil or hearth would be located (Jouttijärvi 2009)). Whilst the evidence presented here in the magnetic susceptibility readings is not conclusive, it is suggestive of the shadow pattern mentioned in publications. Further, the results of Experiment II revealed two conflicting patterns of activity based upon Fe concentrations and magnetic susceptibility readings. Complementary investigation of hammerscale concentration by taking sediment samples or even utilising a magnet to scan the area (*e.g.*, Veldhuijzen 2009a), could reveal the presence of hammerscale, and confirm the magnetic susceptibility enhancements' relationship to the locus and practice of smithing.

The elevated concentrations of Sr, Ca, and K, likely derived from wood and charcoal utilised in the smelting process, in concert with the distribution of increased Rb, Fe, and the magnetic susceptibility enhancement areas—all spatially well-correlated with one another—present a picture of probable metallurgical activity that is ferrous in nature. The inescapable presence of metallurgical debris (partly visible in the foreground of Figure 6.6 image of shaft furnace) in combination with the geochemical and geophysical results from Site A would conclusively identify the site as metallurgically derived. Site prospection and identification are laudable goals, but these data are better served for highlighting the specific arena(s) of production. The restricted nature of the geochemical and geophysical measurements associated with burning, describe well the specific location as well as extent of the pyrotechnical activities. In fact it is only Fe that displays an increased concentration of a broader area that speaks to the breadth of practices (*e.g.*, ore processing, charging, and smithing) associated with the smelt and their resultant impact on the soil.



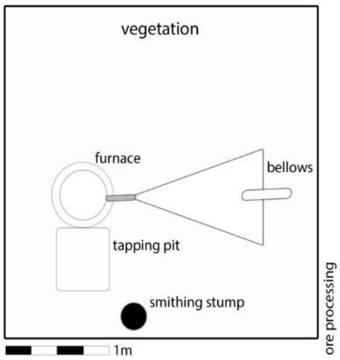
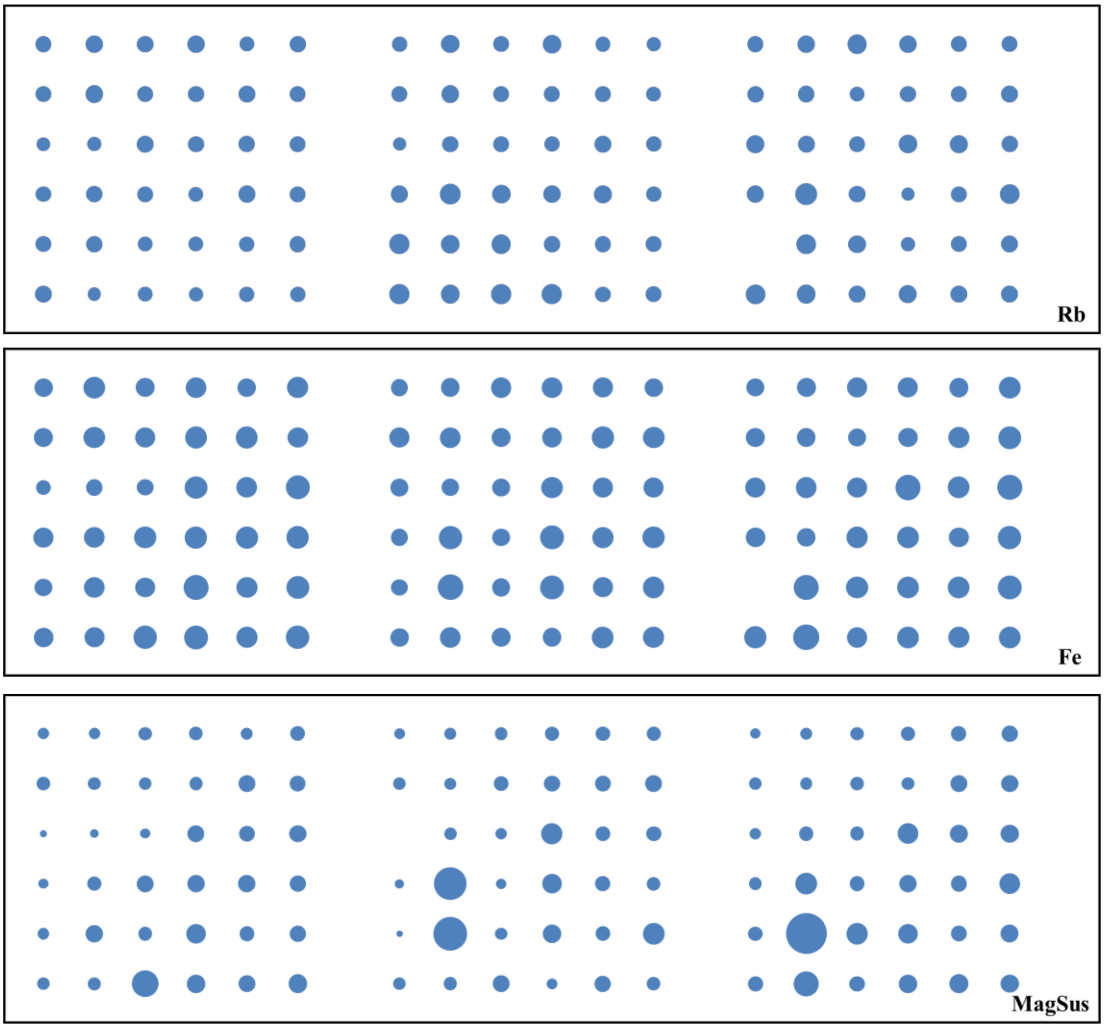


Figure 6.7 Bubble plots of Sr, Ca, and K concentrations from Experiment III Site A, Ecclesall Woods, Sheffield alongside plan of site. ***From left to right:*** **26Oct, 9Nov, and16Nov.**



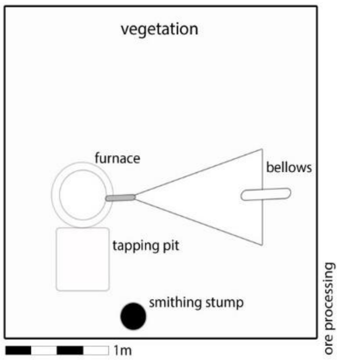


Figure 6.8 Bubble plots of Rb and Fe concentrations and magnetic susceptibility readings from Experiment III Site A, Ecclesall Woods, Sheffield alongside plan of site. *From left to right:* 26Oct, 9Nov, and 16Nov.

EXPERIMENTAL CAMPAIGN B. COPPER-ALLOY METALLURGY

Experiment IV. Copper Smelting

Experimental Design

The first copper-alloy metallurgical experiment took place over the summer of 2012 and utilised a large extended bowl hearth or furnace. The furnace was experimental in design and early experiments explored the possibility of it using natural draft (Figure 6.9) while later attempts employed bellows in a simple configuration (see below).

In addition to geochemical and geophysical surveys being undertaken, the use of space was assessed photographically so as to establish a time-geography analysis of this activity. This analysis was achieved using time-slice photography to carefully record experimenters' practice. These data were then considered in conjunction with the magnetic susceptibility and handheld portable XRF measurements taken *in situ* over the course of the experiment.

Results

GEOCHEMICAL AND GEOPHYSICAL DATA

Geochemical data were gathered via portable XRF (model Niton XL3T) operated as a handheld device; in Soil Mode with a 50 second analysis time (Niton XL3T-HH-Soil-50), while magnetic susceptibility data were collected using a Bartington MS2 Magnetic Susceptibility Meter, *in situ* with a Bartington MS2D Surface Scanning Probe or in the laboratory with a Bartington MS2B Dual Frequency Sensor.

Following an initial 0.25x0.25m survey of the 3x3m site the experimental furnace was constructed. The bowl furnace was large with a 0.60m diameter (Figure 6.9) and the interior was sampled following construction to provide baseline data. After nine pre-firings to ascertain temperature gradients as well as the potential of natural draught and the first smelting attempt utilising chalcopyrite placed in the furnace in shallow crucibles, the site was again sampled *in situ* and recorded as Day13. Further temperature proving experiments and a second smelt were performed following alterations to the well diameter (increased from 0.3m to 1m) and data were taken on Day37. A third smelt was undertaken on Day37 after the survey was concluded and then three days later, geochemical, and geophysical data were recorded for a final time and readings were labelled Day43.

Figure 6.9 ***Clockwise from upper left:*** **Plan of Experiment IV Manor Farm, Sheffield (image by author); image of experimental site with well, furnace, and bellows visible from left to right, with the tarpaulin wind-block in the background (photograph courtesy of B. Comeau); a 3D rendered profile of the a) well, b) tunnel, c) furnace design (image courtesy of D. Pitman); and an image of furnace in the process of being charged with shallow crucible holding crushed ore visible (photograph by author).**

The first two weeks were dominated by temperature proving campaigns that involved the burning of a great deal of wood along with charcoal, with the ashes and unburnt charcoal completely removed at the completion of each trial. In the later stages of the experimental programme, the furnace was never completely cleared and instead temperatures were maintained in the furnace between campaigns by sealing the furnace between trials. This method allowed the experimenters to initiate the next trial on the following day without burning any wood, due to high residual (>600 °C) temperatures that facilitated immediate combustion of charcoal.

Handheld pXRF was used to determine Zr, Pb, Zn, Cu, Fe, Mn, Sr, Rb, Ca, and K. In a manner similar to the experimental activities discussed in the previous experiment, the actions of the experimenters led to significant diminutions in elemental concentrations for a majority of the elements (*i.e.*, Zr, Pb, Zn, Cu, Fe, Mn, and Rb) over the course of the experimental programme. The site of the experiment itself, located in a post-industrial area, was chemically noisy exhibiting high background levels of many elements. Over the course of the experiment the introduction of considerable quantities of clay onto the site for use in construction of the furnace, as well as erosion and redistribution of topsoil due to the inclement weather in July and August 2012 that deposited record amounts of rain upon the English countryside, all aided to mask the initially high baseline chemical signatures. Whilst many elements did decrease overall in concentration over time, it is more notable that the background signature became quieter for many and anomalies associated with experimental activities became more discrete (*e.g.*, Cu and Zn). Further, elements such as Sr, Ca, and K which show marked increases in concentration over time demonstrate patterning that tended to reflect the activities of the experimenters in a convincing manner. Zirconium, Pb, Fe, and Ti were not particularly useful in elucidating practices that occurred on site and their concentrations and patterning were most reflective of the masking effect the high concentrations of Ca and K had on their measurable levels (Appendix A).

Strontium, Ca, and K represent a discrete group of elements recorded on site that were strongly correlated with each other on Day37 and Day43. Strontium exhibits a dramatic increase in elemental concentration on site over the course of the experiment that is wholly associated with experimental features (Figure 6.10). On the initial date of readings, Sr was below the limit of detection, yet by Day37 and Day43 is measurable and spatially well-circumscribed (Appendix A). Following the first two weeks of experimentation the average Sr concentration on site rose only to 27ppm, just barely above the limit of detection, however by Day37 average Sr concentration was 238ppm and by Day43 the average was 358ppm. The striking increase in elemental Sr within the experimental area is also spatially well-correlated with the actions of the experimenters. On Day37 and Day43 there are areas of increased concentration visible both in the location of the furnace as well as the upper right quadrant where hot coals and ash were raked out and deposited. The presence of areas of elevated Sr associated with the furnace and the ash pile is likely the product of the wood and charcoal burned in the furnace and then raked out during the process of charging the furnace. Interestingly there is also a band of low concentration between these two features that corresponds well to where the experimenters walked around the furnace, likely moving ash out of the way.

Calcium levels for the site increased significantly over the course of the experiment, whilst at the same time exhibiting a dramatic shift in the patterning of those concentrations (Figure 6.10). On Day13 a small anomaly is observable on the right side of the site similar to the one visible in the Sr readings, though an increase in Ca concentrations is also beginning to present itself in the upper right quadrant, the location of the ash pile. The concentrations of Ca on Day37 and Day43 are noticeably centred on the location of the furnace and the ash pile in the upper right quadrant as was also the case for Sr. Further, the band of lower elemental Ca concentration is well-defined on Day37 and is still apparent as an area of above average Ca levels (*i.e.*, at least one standard deviation above the mean concentration across the site) on Day43, representative of a measurably lower concentration than the two adjacent areas. The significant increase in elemental Ca over the course of the experiment is most likely derived from the ash, in the form of $CaCO_3$ or CaO dependent upon temperatures achieved (Misra *et al.* 1993), produced by the burning of wood and charcoal in the furnace during the temperature proving campaigns and smelting attempts.

Potassium concentrations at the copper smelting site also increased significantly over the course of the experiment (Figure 6.10). The initial distribution of K on the site is restricted to a few isolated anomalies, yet by Day13 the impact of experimental practice is already apparent in the appearance of an altered distribution of K concentrations with a noticeable area of increased K in the upper right quadrant associated with the location of the ash pile. In contrast to the distributions of Sr and Ca on Day13, K appears to be more responsive to the experimental activities carried out during the first two weeks. The patterning of K concentrations later in the experiment on Day37 and Day43 is much more visually akin to those of Sr and Ca, with noticeable areas of enhancement associated with the location of the furnace and the ash pile in the upper right quadrant. The increased overall concentrations of K witnessed over the course of the experiment are, like the Sr and Ca, derived from the burning of wood and charcoal in the furnace, this time in the form of potash (Etiégni and Campbell 1991, Misra *et al.* 1993, Vassilev *et al.* 2014). The lesser intensity of the K enhancements on Day43 in particular is largely the product of the differing temperatures of volatilisation for K and Ca (*i.e.*, 759 °C and 1484 °C, respectively). As the experimental programme progressed the practitioners were able to better control the temperature in the furnace and regularly sustained temperatures >1000 °C at most points during trials, only allowing the furnace to cool down to around 600 °C between campaigns (Comeau 2012). The differing persistence of K versus Ca in wood ash is borne out by studies that reveal levels of elemental Ca increasing in wood ash as furnace temperatures rise, with K levels decreasing at the same time (Misra *et al.* 1993). It is possible that further research into the relationship between K and Ca concentrations could serve as a potential proxy for furnace/hearth temperatures in the absence of visible architectural remains when pyrotechnical activities are suspected.

Zinc and Cu are the last two elements successfully detected on site that need to be addressed. Zinc as mentioned previously did decrease in overall concentration across the site over the course of the experiment; however anomalies for the element became more discrete and evident against the background levels (Figure 6.11). The pattern of elemental concentration for Zn on Day0 and Day13 is diffuse, but by Day37 structure begins to appear in the patterning of concentrations. There is now a single anomaly visible in the lower left quadrant of the experimental area representing a single reading of 408ppm, yet, the source of the point of high Zn concentration on Day37 is unclear and most likely will remain unexplained. However there are potentially two other areas of increased Zn concentration, one near the bottom centre of the site and the other in the position of the furnace, both of which are associated with locations in which ore was prepared, roasted, smelted, and/or removed from the furnace. The readings from Day43 reveal that the anomaly from Day37 is no longer present. There is now a more pronounced area of enhanced Zn concentration in the area of the furnace, supporting the hypothesis that the source of the Zn was the ore smelted in the experiment. Zinc has a relatively low temperature of volatilisation (*i.e.*, 907 °C) and was likely released as a gas during the smelting process, allowing it to be absorbed by the ceramic furnace structure. In this particular case, Zn might prove a better proxy of the presence of copper smelting due to its lower temperature of volatilisation.

The copper smelting procedure followed during the experiment involved the use of crucibles rather than directly charging the furnace, therefore it is likely that the majority of the copper never made direct contact with the furnace structure. Copper like Zn, exhibits a diffuse pattern of concentrations on Day0 and Day13 (Figure 6.11). On Day13 there is a conspicuous anomaly in the lower right quadrant of the site near to, but not inside of, the furnace, representing a single reading of 818ppm. Additionally there is another area of high Cu concentration towards the bottom centre of the site that is reflects a reading of 371ppm. Both anomalies are linked to experimental practices: the former most likely reflecting lost ore, either from a crucible placed near to the furnace prior to smelting or some unreacted ore removed from the furnace after a smelting campaign, whilst the latter corresponds to the location where chalcopyrite was beneficiated prior to charging crucibles for smelts and it is expected that some ore was lost during this process.

On Day37 Cu levels associated with the furnace itself and the location in which ash was deposited after a smelting campaign begin to discriminate themselves from the background concentrations. Though when measurements were taken on Day37, two smelts had already been conducted, the Cu enhancement within the furnace is still subtle. Any increase in Cu concentrations within the furnace is likely due to ore lost from crucibles either during charging or emptying the furnace and as less than 3kg of chalcopyrite was utilised in each smelt, the external contribution of Cu to the site is limited. On Day43 following the final copper smelting campaign, background Cu levels appear quite similar to those of Day37, yet there is now a readily apparent structured anomaly focused upon the furnace and the area of the site above it. Levels of Cu within the furnace range from undetectable to almost 200ppm; however it is the concentrations outside of the furnace that are more noticeable. Outside of the furnace there is one particular anomaly of 935ppm that is intriguing for not being associated with the area of ore beneficiation, the furnace, nor the ash pile. Only after reviewing notes and the video of the smelting campaign did the source of this seemingly anomalous reading become clear. The location of the high Cu reading is directly correlated with the spot in which a fully charged crucible was removed from the furnace at the end of the campaign and then subsequently knocked over by one of the experimenters. As the ore was not fully reacted (*i.e.*, unsintered), much of the ore fell out of the crucible and was later crushed into the soil of the site. Rather than representing an outlier that needs to be explained away, this anomaly intriguingly captures a facet of practice often ignored, that is, accidental behaviour. Experimental archaeology allows for a focus on the full spectrum of activities associated with metallurgical production and their spatial consequences.

The geochemical appraisal of the site, discussed above, is complemented by the magnetic susceptibility survey. Baseline readings taken on Day0 revealed relatively high but well-distributed levels of enhancement across the site (Figure 6.11). These background levels remained relatively constant over the course of the experiment while anomalies began to present that reflected experimental practice. On Day13 at the very top of the upper right quadrant there is an anomaly with a recorded a value of 1938. Whilst seemingly unrelated to experimental practice centred on the furnace, this area of markedly enhanced magnetic susceptibility is directly associated with the actions of the experimenters. A steel shovel was used throughout the experimental programme to remove hot charcoal from the furnace in order to place and remove crucibles for smelting. After being used in such a manner the shovel would often glow cherry red, and in order to prevent the shovel from starting fires on the site, it was rammed into the ground near the edge of the experimental area. The heat of the shovel, most likely upwards of 700 °C, based upon the relationship between iron colour and temperature (Rehder 2000: 12), could easily influence the magnetisation of the soil in which it was placed. This particular enhancement could easily be dismissed as anomalous given its lack of correlation with any known centre of production on the site, but the process of experimentation has clearly shown the diversity of productive practices that can be overlooked in discussions that fail to acknowledge agents and their capacity for action and choice in all its forms. Aside from this very noticeable point of enhancement there are the beginnings of what could be a structured anomaly at the edge of the furnace and in the area of the ash pile. By Day37, however this patterning of enhancement is unmistakeable and well-correlated with areas of experimental practice. The footprint of the furnace is now readily apparent in contrast to background magnetic susceptibility levels and there are further points of enhancement in the area of the ash pile, including one particularly high reading of almost 8000. This particular anomaly is challenging to reconcile—its position in the location where hot coals were removed from furnace on to the soil is not surprisingly an area that would show increased magnetic susceptibility. Yet, this level of enhancement is exceedingly high (Powell *et al.* 2002) and is curiously associated with an elevated Cu concentration (221ppm), suggesting that perhaps rather than getting a direct reading of the soil, the probe recorded a magnetic susceptibility value for a piece of one of the crucibles that had been removed from the furnace and fractured on the ground, explaining both the presence of the Cu and the marked magnetic susceptibility enhancement. On Day43, the same magnetic susceptibility anomaly is present, albeit at a considerably lower level of enhancement (3086) alongside a Cu reading of 150ppm, which is similar to those recorded within the furnace. On Day43 the magnetic susceptibility survey again illustrated well the location of the furnace due to the presence of a set of structured anomalies. Aside from the previously mentioned anomaly from Day37 and Day43, there is another anomaly near to the edge of the well at the centre of the site directly adjacent to the Day43 Cu anomaly (935ppm) referenced earlier that directly reflected the location of a crucible that was spilled and broken directly after removal from the furnace.

The geophysical survey of the experimental area was predictably most adept at resolving the location of the furnace which was the site of sustained pyrotechnical activity over the course of six weeks. The recordings taken on Day37 and Day43 at the end of the experimental programme revealed an area of significantly enhanced magnetic susceptibility that was visually well-correlated with the areas of increased Sr, Ca, and K concentrations. Whilst magnetic susceptibility is best at illustrating the location of the furnace, both the geophysical and geochemical methods have both reflected the area of the site where hot coals and ash were removed from the furnace. Strontium, Ca, and K have excelled as proxies for experimental practice that involves the burning of wood and charcoal, however the lasting impact that these elements would have on the soil is nowhere near that of heavy metals. However, these elements were adept at revealing past practice in their distributions on site and notably in their absence. The path taken by the experimenters between the furnace and the ash pile was seen in the patterning of Sr, Ca, and K, making manifest the actions of the practitioners as they engaged with the furnace. Further the location of the ash pile in relation to the furnace indicates the handedness of the experimenter as he or she shovel out the hot coals and purposefully tossed them to the right. Copper and Zn in particular were successful in illustrating the location of the furnace and additionally serve as key indicators of the metallurgical process that was carried out within that structure. Additionally both Cu and magnetic susceptibility readings were able to reveal aspects of practice outside of the typical *chaîne opératoires* of metallurgical production. When cognisant of the breadth of practices that can be captured by their geochemical and geophysical signatures it becomes possible to consider a less constrained view of past practice.

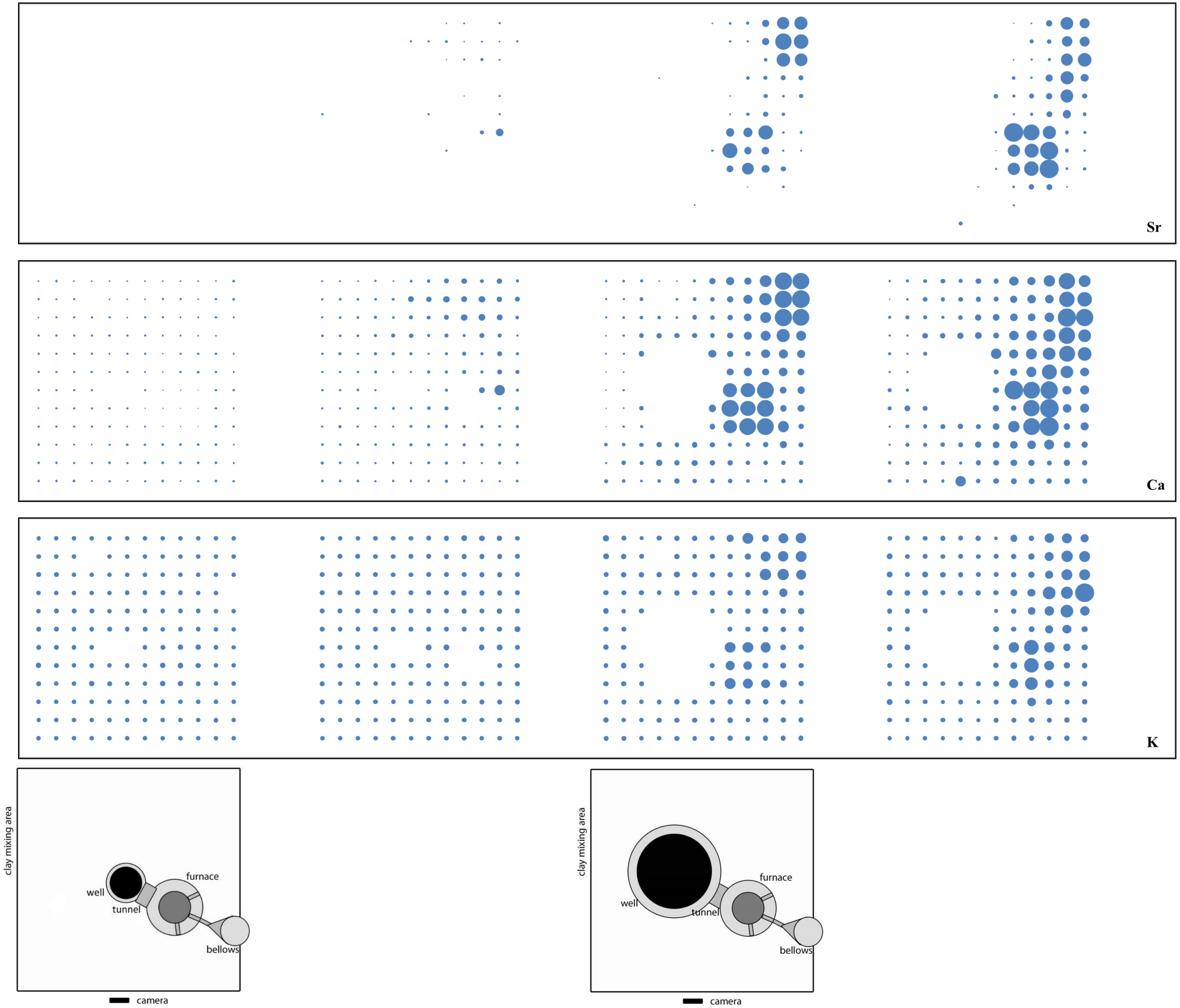


Figure 6.10 Bubble plots of Sr, Ca, and K concentrations from Experiment IV Manor Farm, Sheffield alongside plans of the site with 0.3m (*left*) and 1m (*right*) diameter wells. From *left* to *right*: Day0, Day13, Day37, and Day43.

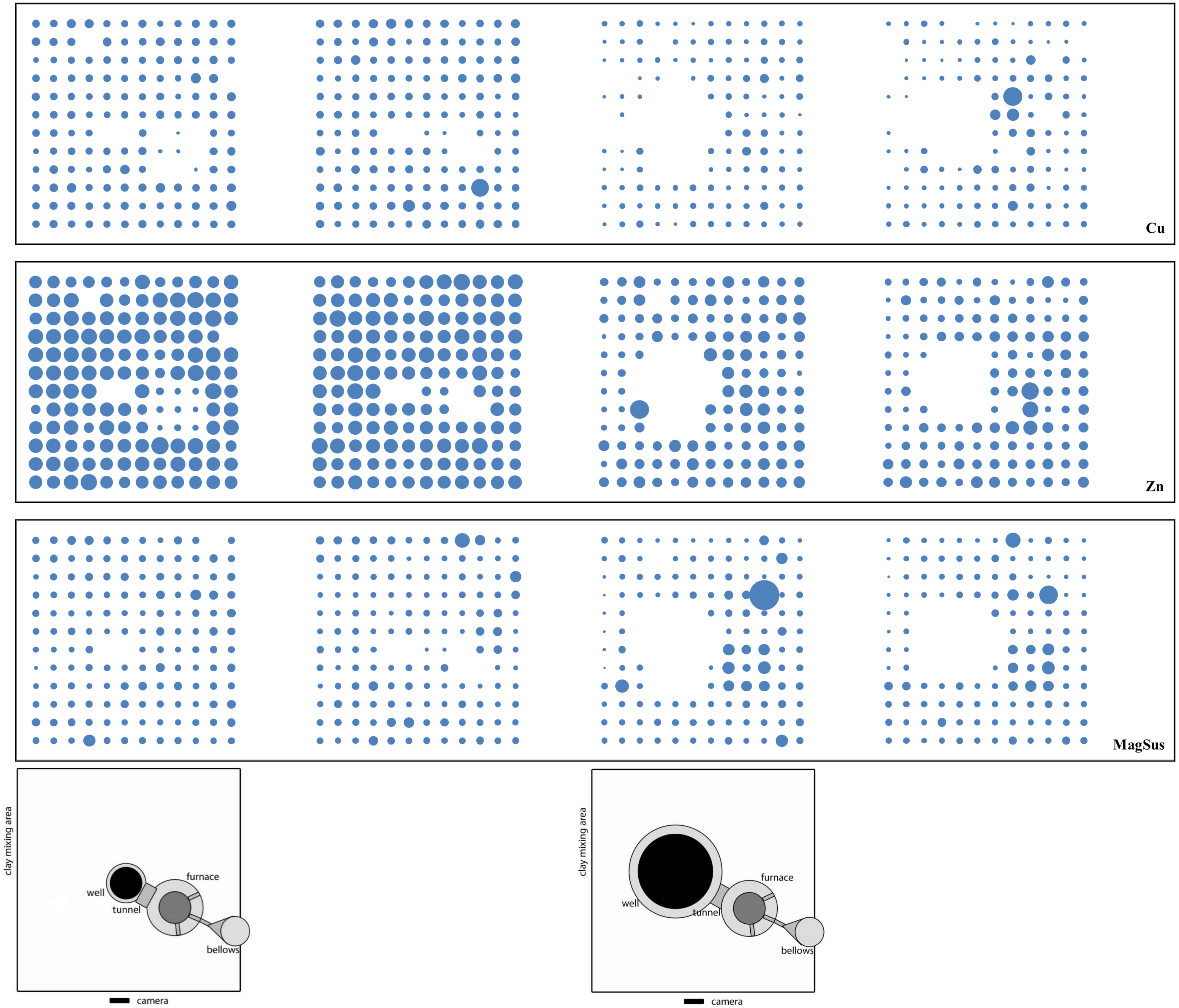


Figure 6.11 Bubble plots of Cu and Zn concentrations and magnetic susceptibility readings from Experiment IV Manor Farm, alongside plans of the site with 0.3m (*left*) and 1m (*right*) diameter wells. *From left to right:* Day0, Day13, Day37, and Day43.

TIME-GEOGRAPHY DATA

In the context of Experiment IV the technique of time-geography was utilised alongside geochemical and geophysical survey to examine how two experimental practitioners used space for the duration of the experiment. The spatial dimension of the time-space map of performance was necessarily limited. The site was 3x3m and only activities occurring within that area were recorded. The experimental area was restricted not simply to facilitate the sampling and recording of geochemical and geophysical data but more critically to simulate the constraints of an interior space where the hearth could have been operated. Whilst it was not feasible to conduct the experiment indoors, windbreaks in the form of multiple tarpaulins were erected around the furnace and well to control the effects of wind on the structure. The small size of the experimental arena put additional ‘packing capacity’ constraints (Giddens 1985: 266) upon the participants, leading them to rapidly learn to negotiate both the limited space and the immediate dangers of a well and a furnace operating in excess of 1000 °C.

The furnace was typically operated by two primary individuals, though other volunteers did participate at times. Through analysis of the time-slice photography, it is apparent movement within the space was defined not by the practitioners but by their practices. There were two primary roles delimited in space, or more accurately, the roles described two *places* (Giddens 1985) within the arena of performance. These roles, which were immediately apparent when viewing footage of the furnace being operated solely with a set of bellows, were filled by both individuals at varying points over the course of the day (Figure 6.12). However the introduction of new practices (*i.e.*, utilising a bucket in the well to attempt to act as a piston to drive air into the furnace or the emptying of the furnace prior to and after smelts) led to a shift in the loci of places within the experimental area (Figure 6.13, Figure 6.14, and Figure 6.15). The way in which practices were divided suggests that rather than being able to study specific individuals we can only observe the results of their actions, which in the case of this experiment were not specific to the particular individuals. It is of course entirely possible and plausible that the roles that the two experimenters shifted in and out of would have been more fixed for ancient practitioners more specialised in their crafts. However, certain capability constraints do come into play (Hägerstrand 1970, Pred 1977, Giddens 1985). Operating the bellows continuously for over one hour leads to fatigue as well as general discomfort from sitting on the ground, the high temperatures add to this discomfort although comfort thresholds are heavily reliant on cultural norms and conditions. In the absence of non-human powered bellows it seems self-evident that the individual operating the forced draught would have to change periodically due to these basic constraints on the capabilities of the human body.

That the two separate zones of space were chosen, or rather two separate *places,* when operating the furnace with limited overlap may be considered significant. These roles were never discussed and simply emerged through practice as an understanding of the space and performance of the furnace developed. It was also noted that often the arrival of third person to assist disrupted the usual rhythm of work, leading to repetition of activities on another day when the extra person was not present.

Geochemical survey of the site, conducted following the smelting campaigns, revealed notable correlations between certain actions performed by the experimenters recorded by time-slice photography and the concentrations of elements detected in the soil (see above). Further correlations were revealed between magnetic susceptibility measurements (Figure 6.11) and our recorded actions; in particular, the removal of charcoal and ash from the furnace, to facilitate the placement and retrieval of crucibles as seen in Figure 6.15.

Further to the information gained via the geophysical and geochemical survey as well as time-slice photography, there are physical constraints upon the human body that cannot be discounted and must be acknowledged within experiments. It was also notable that despite the similar operating temperatures of the low squat furnace used in this experiment and other shaft furnaces operated, it was quite difficult to approach this furnace during a smelt as the apparent heat intensity was much higher, likely a product of the greater radiant area and the low sitting form of the furnace. It suggests that specific bodily practices are appropriate to specific furnace forms.

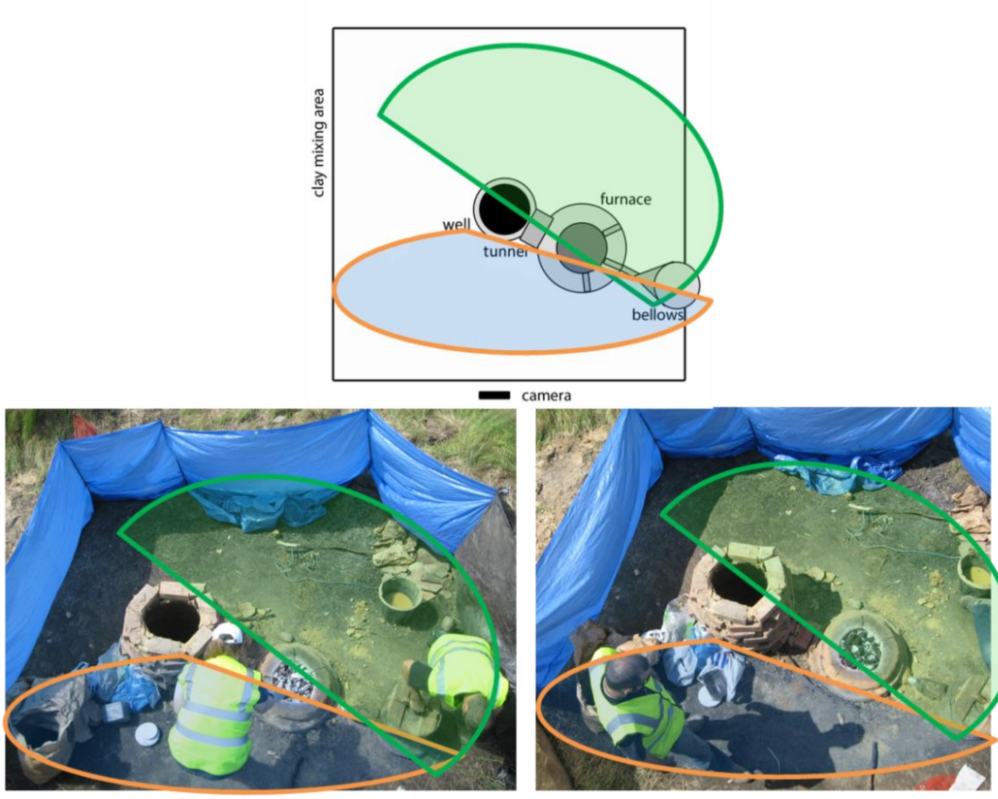


Figure 6.12 Plan of Experiment IV furnace above two images of the furnace in operation showing two *places* outlined in green and orange corresponding to two roles that were filled interchangeably by both practitioners when the bellows were utilised as the sole source of forced draught (image and photographs by author).

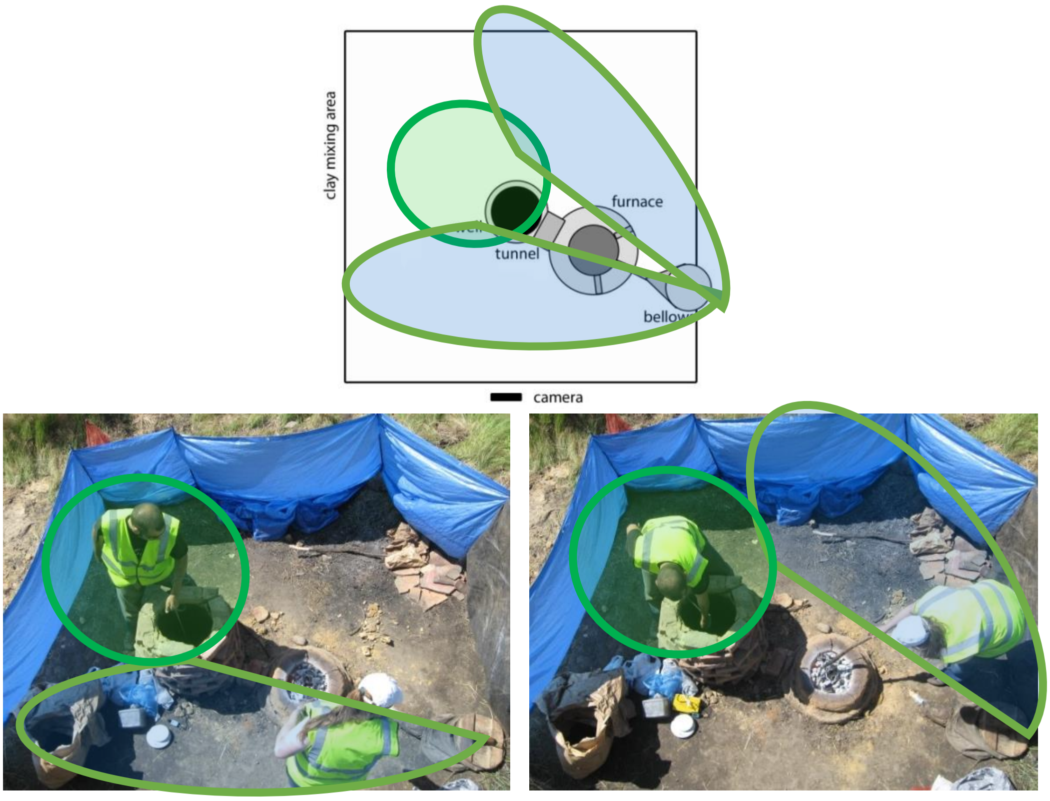


Figure 6.13 Plan of Experiment IV furnace above two images of the furnace in operation showing two different *places* outlined in green and orange corresponding to two roles that were filled interchangeably by both practitioners when the bellows were not in operation and the well was being utilised to force draught (image and photographs by author).

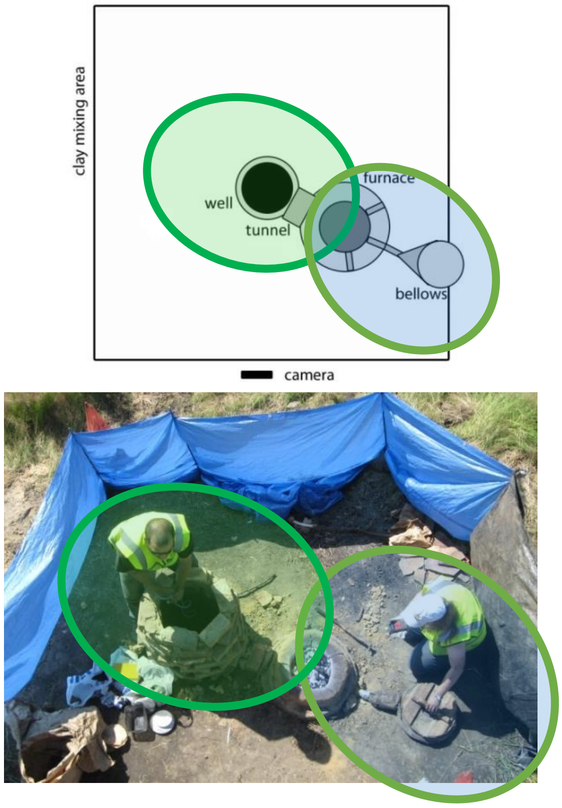


Figure 6.14 Plan of Experiment IV furnace above an image of the furnace in operation showing two different *places* outlined in green and orange corresponding to two roles that were filled interchangeably by both practitioners when the bellows and the well were being utilised together to force draught (image and photograph by author).

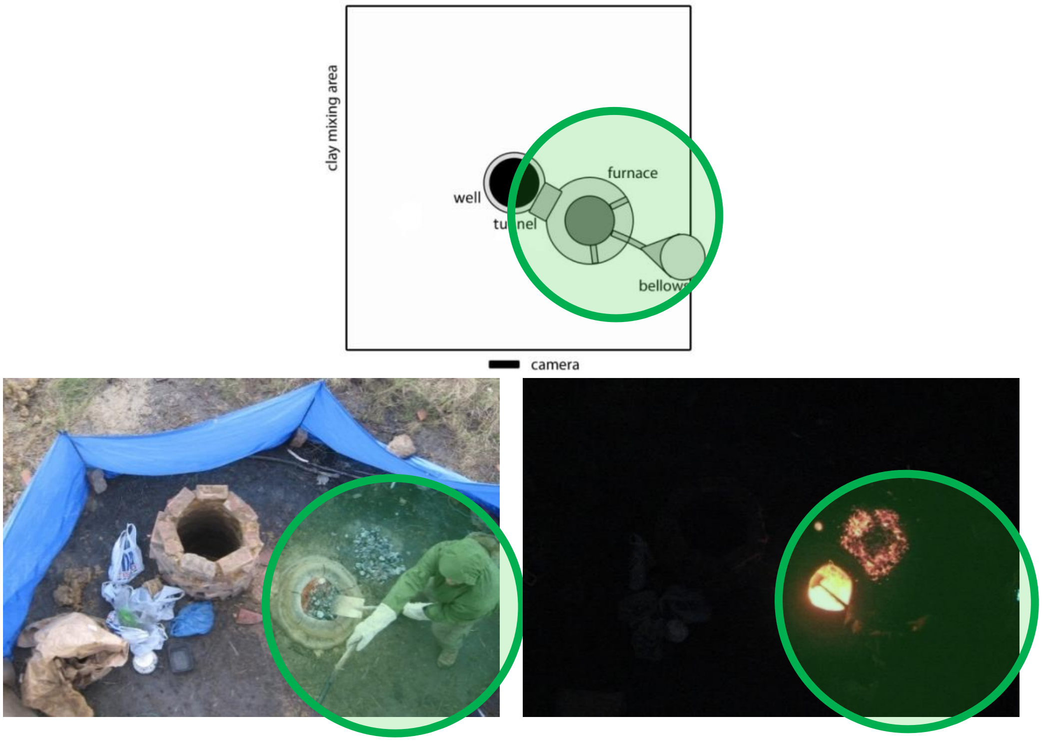


Figure 6.15 Plan of Experiment IV furnace above two images of furnace in operation showing a single *place* outlined in green corresponding to the role that was filled by one practitioner when the furnace was being emptied of hot coals and crucibles (image and photographs by author).

Experiment V. Copper Smelting & Casting

Experimental Design

Over the course of three weeks in Autumn 2012, three experiments involving the smelting, melting, and casting of copper-alloys were carried out at J G Graves Woodland Discovery Centre, Ecclesall Woods, Sheffield, UK. A 2x2m area, designated Site B, was cleared of branches and other large items of natural debris (*i.e.*, leaf litter), yet naturally through the course of the experiment this material was redistributed) and a shallow hearth was constructed of coal measure clay within the centre of the area (Figure 6.16). The smaller size of Site B in comparison to Site A was necessitated by the layout of the space available rather than a conscious decision to further limit the experimental survey area. Sampling resolution was kept at 0.5x0.5m.

In a conscious decision, the clay utilised for the hearth and crucibles was spiked with Cr_2CO_3 at levels at least an order of magnitude above natural (*i.e.*, >1000ppm) (BGS 2014: 126-128, Salminen *et al.* 2005). Chromium additions meant that clay, a challenging material to trace geochemically, could be tracked easily as it was distributed through a number of processes.

Date	Activity
2 Nov	cuprite smelting, melting, & casting
9 Nov	copper alloy melting & casting
16 Nov	copper alloy melting & casting

Table 6.3 Metallurgical activities performed as part of Experiment V Site B, Ecclesall Woods, Sheffield.

The smelting, melting, and casting activities undertaken at Site B (Table 6.3), occurred over a period of two weeks, allowing the experimenters to measure changes in geochemical and geophysical readings over time and to witness how metallurgical activities impact the soil and subsequently those measurements. Geochemical data were gathered with a Niton XL3T used as a benchtop unit with a He purge in Mining Mode with a 90 second analysis time (Niton XL3T-BT-Mining-90), while magnetic susceptibility data were collected using a Bartington MS2 Magnetic Susceptibility Meter in the laboratory with a Bartington MS2B Dual Frequency Sensor. Prior to commencement of metallurgical activities, the 2x2m site was surveyed along 0.5m transects at 0.5m intervals. These data were recorded as 26Oct for the site. Data were then taken on 9 November (9Nov) following the first metallurgical event of 2

Figure 6.16 ***Clockwise from upper left:*** **Plan of Experiment V Site B, Ecclesall Woods, Sheffield (image by author); image of copper casting (photograph courtesy of J. Karjalainen); image of hearth and two sets of single chambered bag bellows as well as the upper casting area with used and unused crucibles visible (photograph by author); image of crucible charged with pieces of copper-alloy being placed in the hearth (photograph by author; and .image of cuprite in crucible ready for placement in hearth (photograph courtesy of J. Karjalainen).**

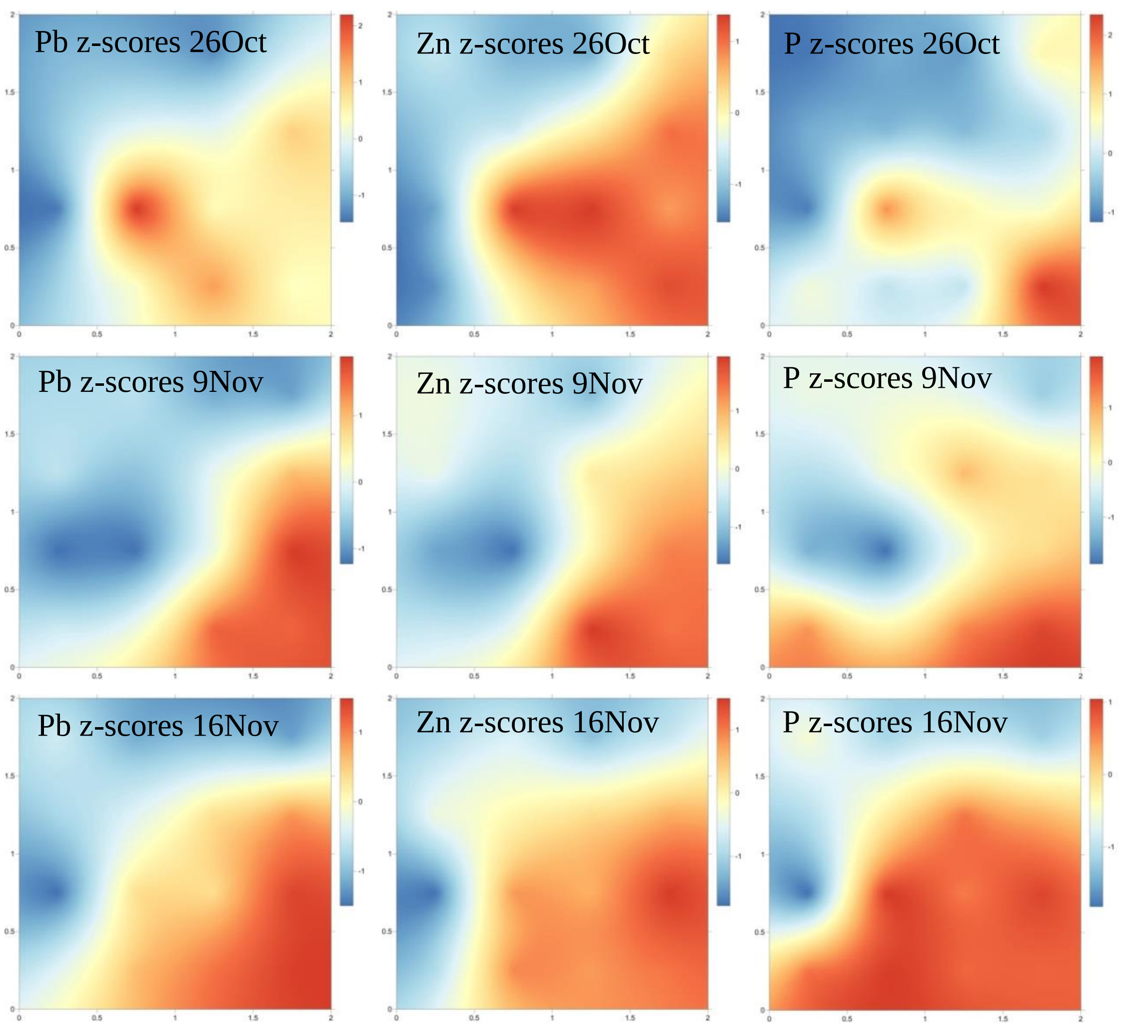
November and on the evening of 16 November following the metallurgical activities which occurred on 9 November and 16 November (16Nov). Due to equipment availability all samples were collected in the field to be analysed *ex situ*. Samples were processed in the laboratory, where they were dried overnight in an oven at 75 °C, ground into a fine powder, and then placed in sample pot covered with a 4μm proline window and weighed prior to pXRF and magnetic susceptibility measurements.

Results

Portable XRF determinations were made of Zr, Sr, Rb, Pb, Zn, Cu, Fe, Mn, Cr, Ca, K, and P, with only significant elements reported here (see Appendix A for other data). There was a similar pattern observed for a number of the elements in their baseline pXRF readings that suggests an underlying geological (or potentially anthropogenic) structured anomaly. Most notably the readings for Pb, Zn, and P exhibit this structured patterning over the course of the experiment and appear uninfluenced by the metallurgical practices over the course experiment (Figure 6.17).

Measurements for Cu and Ca, as well as magnetic susceptibility readings, are potentially illustrative of the arrangement of the experimental space as well as the activities that took place within it. Copper did appear to increase in concentrations over the course of the experiment, as one would expect to see after the three campaigns of copper-alloy metallurgy. The increased concentrations are centred on the location of the hearth reflective of the suite of metallurgy activities (*e.g.*, casting) which were not restricted to the hearth itself. Yet, with only 16 samples taken to assess the experimental area, these points of increased concentration though associated with known activities do little to reconcile how the experimenters actually engaged with the hearth. Additionally the small size of the hearth (*i.e.*, approximately 0.25m in diameter) and the restricted quantities of copper ore and copper-alloy (*i.e.*, <0.5kg cuprite and <5kg of copper-alloy) as well as the use of crucibles in the smelting/melting process (as noted for Experiment IV), rather than a directly charged furnace as utilised in Experiments I and III further prevents Cu from directly influencing the surrounding soils.

Calcium displayed a pronounced change in distribution of elemental enhancement as well as a subtle increase in concentrations that is most apparent in the lower left quadrant in relation to the hearth. This increase in Ca concentration for the site is most likely the product of ash from the burning of wood and charcoal in the shallow hearth (Canti and Linford 2000). Though the Ca readings aid in illustrating the location of the hearth within the site, on their own they can do little more than indicate an activity took place which contributed excess Ca to the system. Unfortunately as a naturally abundant element (BGS 2014), Ca enhancement is equally likely to be of geogenic or anthropogenic origin without further contextual evidence. Magnetic susceptibility quite convincingly provides contextual evidence, revealing that both Ca and magnetic susceptibility enhancements are demonstrated for the same locations on 16Nov in the area correlated with the hearth. However the points of enhancement on 16Nov are within or very near the range of the initial baseline readings, though there is an observed decrease in enhancement on 9Nov. The low level magnetic susceptibility enhancements observed could be due to the location of measurements, as it is entirely possible that either the interior of the hearth was not sampled, or the temperatures encountered in the hearth though significant (*i.e.*, >1000 °C), were not of the sustained nature of those of the shaft furnace and thus did not impact the surrounding soils as noticeably.



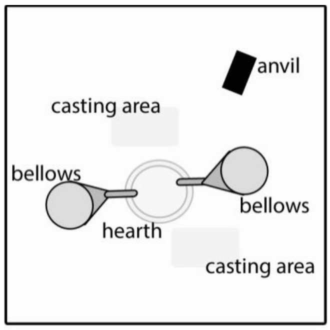
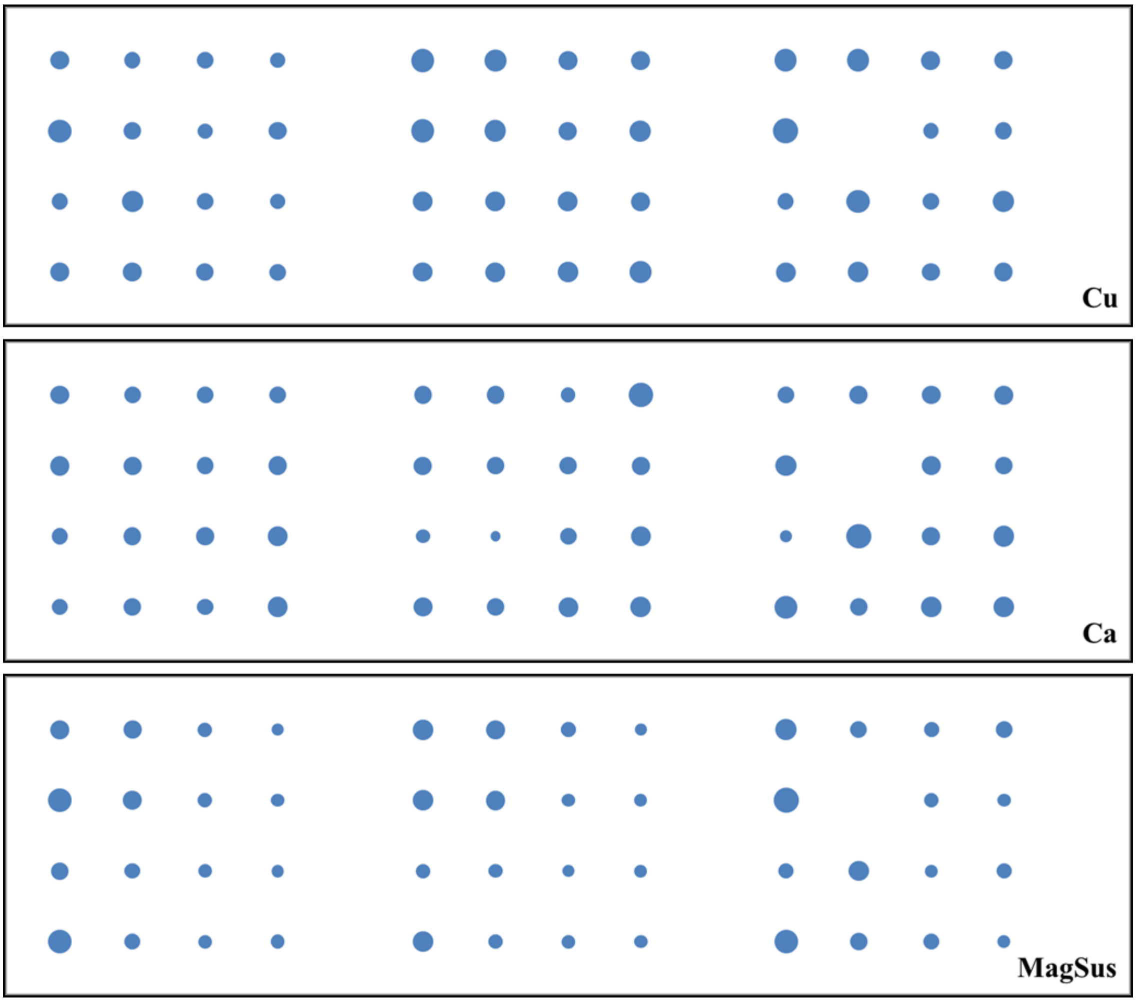


Figure 6.17 Rasters of Pb, Zn, and P z-scores for Experiment V Site B, Ecclesall Woods, Sheffield alongside plan of site. Interpolated images produced via ordinary kriging utilising Surfer 11.6.1159.

Chromium is the last element to be discussed in relation to Experiment IV. As mentioned previously the clay used in the construction of the hearth and the crucibles was doped with Cr_2CO_3 in order to potentially witness the movement of clay, a notoriously difficult material to track, around Site B. Unsurprisingly, Cr levels demonstrated a considerable increase in concentration over the course of the experiment. At the basest level these data prove that the Cr_2CO_3 laden clay successfully contributed to the system of the experimental area in a manner detectable by pXRF. More specifically the changing pattern of Cr concentration across the site over time is a means of detecting not only the placement of the hearth and broken crucibles, but also the movements of the experimenters who inadvertently tracked clay upon their boots as they traversed the site. The distribution of Cr is well-correlated with the position of the hearth as well as the lower casting area. Overall, despite Cr not being directly related to the metallurgical activity carried out on site, its presence served as useful proxy of those practices exhibiting similar patterns of enhancement to Ca, Cu, and magnetic susceptibility.

The Ca, Cu, and magnetic susceptibility readings are associated with and attributed to the presence of the copper smelting/melting hearth. In concert with the conspicuous metallurgical activity in the form of crucibles and runlets (Figure 6.16), these patterns of enhancement help to craft a signature of practice. Whilst the manipulation of the source clay utilised in the experiment to contain Cr nature cannot be easily replicated and has no clear parallels with archaeological data, it does serve to illustrate the impact practice, expressed through the movements of the experimenters as they engaged with the metallurgical process, can have upon the geochemistry of the soil.



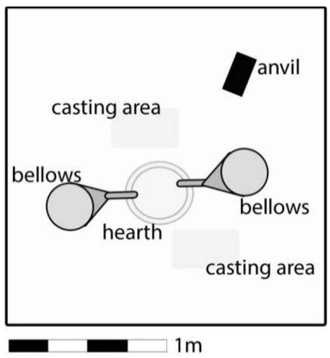


Figure 6.18 Bubble plots of Cu and Ca concentrations and magnetic susceptibility readings from Experiment V Site B, Ecclesall Woods, Sheffield alongside plan of site. *From left to right:* 26Oct, 9Nov, and 16Nov.

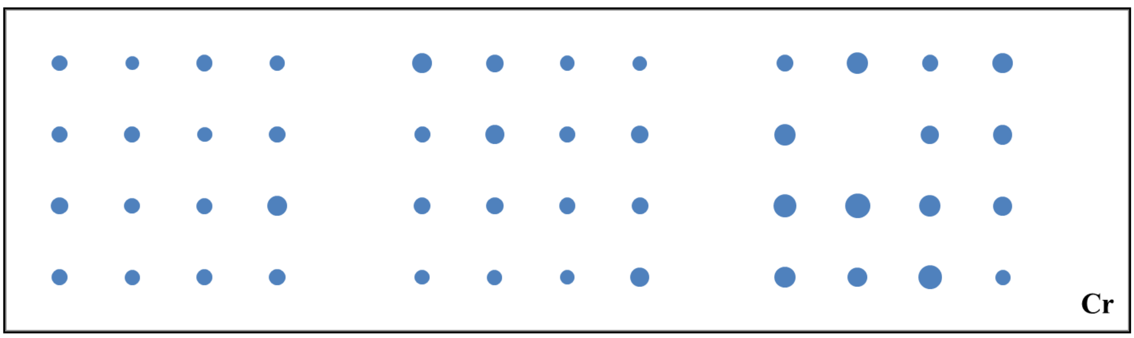


Figure 6.19 Bubble plots of Cr concentrations from Experiment V Site B, Ecclesall Woods, Sheffield. *From left to right:* 26Oct, 9Nov, and 16Nov.

EXPERIMENTAL CAMPAIGN C. HIGH-TEMPERATURE NON-METALLURGICAL ACTIVITY

Experiment VI. Cooking fire

Experimental Design

A final experiment was conducted as a non-metallurgical control in Autumn 2012 at J G Graves Woodland Discovery Centre, Ecclesall Woods, Sheffield, UK on the final day of the three week programme of experimentation. A 2x2m area, designated Site C, was selected in an area of woodland that had not been previously disturbed by any high-temperature experimental activities. The area was cleared of branches and other large items of natural debris. The plan for Site C involved the construction of a small campfire which would burn for a couple hours and be used for the cooking of pork products and bread (Figure 6.20). Geochemical data were gathered with a Niton XL3T used as a benchtop unit with a He purge in Mining Mode with a 90 second analysis time (Niton XL3T-BT-Mining-90) while magnetic susceptibility data were collected using a Bartington MS2 Magnetic Susceptibility Meter in the laboratory with a Bartington MS2B Dual Frequency Sensor.

Figure 6.20 Experiment VI Site C, Ecclesall Woods, Sheffield (*left*) image of students cooking over the small campfire (photograph by author) and (*right*) close-up image of meat and bread being cooked over the small campfire (photograph courtesy of J. Karjalainen).

To determine the geochemical and geophysical impact on the soil, the area was surveyed before and after the experiment along 0.5m transects at 0.5m intervals and recorded as AM and PM. An attempt was made to take pXRF readings in the field, however the high organic content of the soil proved problematic for the device and instead samples were collected, as done for Site A and Site B, to be analysed *ex situ*. Samples were processed in the laboratory, where they were dried overnight in an oven at 75 °C, ground into a fine powder, and then placed in sample pot covered with a 4μm proline window and weighed prior to pXRF and magnetic susceptibility measurements.

Results

The pXRF measured Mo, Zr, Sr, Rb, Pb, As, Zn, Cu, Fe, Mn, Cr, V, Ti, Ca, K, S, Cd, Ag, Pd, Nb, Al, P, Si, and Cl in the soil of the experimental site at levels above their limits of detection. The soil in this area of woodland was high in organic matter, and detected element concentrations were nearly all lower than those recorded in Site A and Site B (see Appendix A). Similar to many of the previous experiments, a number of elements were un-responsive to the activities performed within the site, serving to illustrate underlying geogenic, or pre-existing anthropogenic geochemical variation. Of those elements whose distributions were altered by the experimenters' activities many were the same as those affected by high-temperature metallurgical processes (*e.g.*, Ca and K). Of the elements that were successfully detected (see Appendix A) only those elements that offered interpretative value (*i.e.*, Ca, K, and P) are reported here alongside magnetic susceptibility readings.

Calcium, K, and P did not dramatically increase in concentration between the two readings, yet all three did present anomalies in the same area to the left of where the centrally located fire was constructed on Site C. All three elements also demonstrated a single anomaly in the bottom right corner of the site. Though this spot of enhancement was not directly related to the location of the campfire utilised for this experiment, its appearance in the distributions of multiple elements is suggestive of it being the result of the experimenters' interventions. The combination of elements presenting the anomaly would support ash as the source of the area of enhancement (Etiégni and Campbell 1991, Siddique 2008). In an effort to put out the fire at the end of the experiment, it is possible that ash was redistributed around the site. Intriguingly, the same anomaly is exhibited in the magnetic susceptibility readings, whilst at the same time there is no evidence of enhancement towards the centre of the site in association with the fire. This lack of an enhancement associated with the cooking fire is not surprising as the Curie points for iron oxides (*i.e.*, 565-675 °C), are not typically met for general cooking or camp fires (Gaffney and Gater 2003, Canti and Linford 2000). However this does little to explain the observed magnetic susceptibility anomaly. It is difficult to imagine a scenario in which entirety of the magnetically altered topsoil was completely redistributed to the lower right quadrant, whilst leaving significant quantities of ash in the centre of the area to register increased concentrations of Ca, K, and P or that there was a particular event that occurred solely in the corner of the site which served to preferentially enhance magnetic susceptibility. Another somewhat inexplicable observation is the increased concentration of P correlated with the fire location on Site C, whilst for Experiment III and Experiment V no similar increases in P concentration were demonstrated (see Appendix A). Too much meaning should not be read into this difference in patterning. The activities considered in Experiments II, V, and VI only were highly ephemeral and the ability of techniques such as pXRF to detect any changes in concentration in lighter elements is noteworthy, yet not infallible. These differences in detection are likely within the realm of variability when sampling at 0.5x0.5m resolution, as well as utilising multiple individuals in the collection of soil samples.

In combination, the patterns of enhancement for Ca, K, P, and magnetic susceptibility are suggestive a process that produced ash yet was not of significantly high-temperature to impact the magnetic enhancement of the soil. Further, in the absence of metallurgical debris as well as any significant concentration of heavy metals it is possible to dismiss metallurgical processes as the source of the patterns revealed in the geochemical and geophysical data.

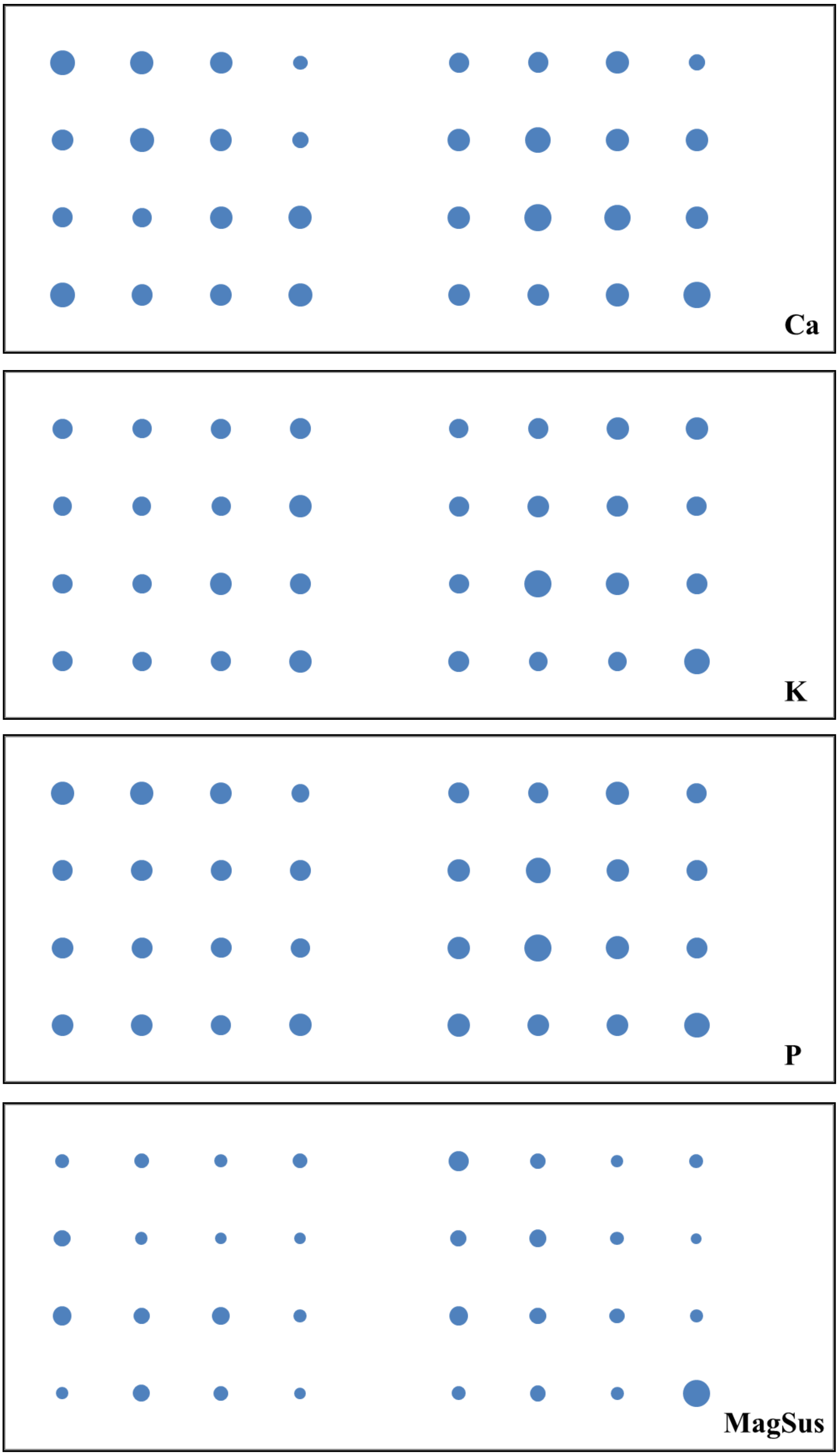


Figure 6.21 Bubble plots of Ca, K, and P concentrations and magnetic susceptibility readings from Experiment VI Site C, Ecclesall Woods, Sheffield. ***From left to right:*** **AM and PM.**

SUMMARY

The experiments considered herein have focused on the application of pXRF and magnetic susceptibility both *in situ* and *ex situ* to contexts of ferrous and copper-alloy metallurgy as well as high-temperature non-metallurgical activities. Surveyed at varying scales of resolution the experiments served to detail the capability of both techniques to recognise the impact of known processes on open soil contexts.

Heavy metals, Cu and Fe in particular, were not always the most adept at illustrating experimental activities on site. Iron was generally able to locate the position of furnaces but was less sensitive to smithing activities. However, the specific loci of copper alloy metallurgy were more difficult to recognise with elemental analysis of heavy metals. The extended bowl hearth utilised in Experiment IV was discernible based upon Cu and Zn concentrations after three smelting campaigns yet the Experiment V's hearth was largely undetectable after a similar number of smelts and/or casts. The anomaly visible in the data from Experiment IV is much more structured and compelling, whilst the single Cu anomaly for Experiment V does corroborate the function of the hearth it is not as convincing an indicator of practices on site. The two different pictures presented by the data from these experiments are likely the result of either sampling resolution (*i.e.*, Experiment IV -- 0.25x0.25m and Experiment V -- 0.5x0.5m) or perhaps a product of differing durations of experimentation (*i.e.*, 6 vs. 2 weeks). Further, the inability to reliably detect furnace architecture through heavy metal analysis puts more weight on the importance of accompanying artefactual evidence for the identification of contexts of past practice. Copper too was able to reveal the location of the hearths utilised in Experiment IV and Experiment V.

Across all experiments it was not the presence of heavy metals in the soil that was most indicative of past practice in spite of the variety of metallurgical activities undertaken. Strontium, Ca, and K, introduced into the environment as components of wood ash, were particularly adept at demonstrating the location of high-temperature processes and their by-products. Though Ca is a major element present in the Earth's crust at levels around 3 percent (Salminen *et al.* 2005: 97) the strongly visible correlations between these three elements make it difficult to dismiss the signatures of Ca concentration as background noise. The influence of these elements on the soil, often spread beyond the confines of the furnace or hearth, and demonstrated an ability of elemental analysis to highlight where coals or ash were deposited. An interesting feature of the enrichment of sites' Sr, Ca, and K through wood ash was the material's mobile nature. Though wood ash was often deposited in particular locations at the experimental sites, it was dispersed by the movements of the experimenters providing a means of highlighting the pathways taken when traversing the sites. For Experiment IV in particular, these elements illustrated areas of high traffic around a furnace with contrasting levels of high and low concentration, as well as an intriguing capacity to indicate handedness of an experimenter. Alone, these elements are of course only indicators of past burning but along with evidence of heavy metals as well as any macroscopic debris or preserved metallurgical features, these elements can reveal composite signatures that can be used as reliable indicators of practice.

Magnetic susceptibility proved a reliable indicator of furnace and hearth locations as well as ore and slag spreads; convincingly detecting the locations of furnaces, hearths, and fires in all but one experiment. The patterns of enhancement demonstrated by magnetic susceptibility often provided confirmation of the structured rather than random nature of anomalies. As has become evident, no one element or even one technique is capable of resolving metallurgical activities. Together with other forms of evidence, pXRF and magnetic susceptibility readings provide middle-ground, linking metallurgical features to the products of those features. For instance, by comparing magnetic susceptibility readings and Sr, Ca, and K concentrations, a common correlation is observed between the two sets of data, however, at times the areas of magnetic susceptibility enhancement do not cover the same extent as those of the elements. It is hypothesised that this mismatch of anomalies is indicative of the process of removing hot coals from furnaces or hearths. As this extremely hot material touched the ground it enhanced the magnetic susceptibility of that location, but as these coals and wood ash cooled and later spread, they did not serve to enhance magnetic susceptibility and only impacted the concentrations of the aforementioned elements. This sequence of events was confirmed during Experiment IV as captured in the still photography (Figure 6.15), which reveals hot coals being removed from the hearth and placed quite close to the structure, then later moved to the upper right quadrant of the site. Illustrative of how these data can at times, highlight less enduring routine actions such as the clearance of a furnace and even the bodily manner in which it occurred.

The fact that no one element, or even technique, can present a fully nuanced illustration of the activities and practices that occurred on site is readily apparent in the results of all three ferrous smelting experiments. Sampling resolution was an important factor that was considered over the course of the experimental campaigns. In Experiment I, the decision to increase resolution from 2x2m to 1x1m for the final survey was precipitated by preliminary analysis of both the geochemical and magnetic susceptibility data which was unable to locate either of the two furnaces. The finer resolution of the final survey was apparently more successful at resolving the pyrotechnical features in the form of Fe anomalies around the bowl furnace and magnetic susceptibility anomalies well-correlated with both the bowl and shaft furnaces. The increased visibility of these features is unlikely to be due to any changes in soil composition or physical properties over the course of the two weeks between readings, and more likely reflects the difficulty of capturing geochemical and magnetic susceptibility patterning from roughly 0.03x0.03m scraped samples within a 2x2m unit. Experiment III, which sampled at an even finer resolution of 0.5x0.5m, was able to indicate the location of the furnace and/or slag pit with both Fe concentrations and magnetic susceptibility readings. Additionally, the depth of time considered for the varying experiments had an apparently positive correlation with the results of geochemical and magnetic susceptibility analysis, with the experiments repeated the least showing the least impact upon the geochemical and geophysical data.

An increased understanding of the importance of practitioners' bodily performance in metallurgical production is one of the measurable outcomes of this sort of experimentation. The time-geography approach used in Experiment IV to complement geochemical and magnetic susceptibility data seemingly is only applicable to sociological or anthropological studies, yet can indeed give us insight into the remote past. The analysis of how two experimenters engaged with a metallurgical activity in time and space, illustrates how practice is less about individuals but rather processes and ways of going on. Experimentation can reveal that certain repeated actions, for example the emptying of a hearth or the repeated path taken by an individual across a site, do impact their environment and can be detected by archaeological means. Further, by demonstrating that the paths of individuals are often difficult to disentangle, the activities performed by them that impacted the soil become less a record of past people and rather past practice.

Chapter 7. Archaeological Methods & Results

INTRODUCTION

This chapter presents the results of the archaeological analysis of a number of key sites that have produced evidence of Iron Age metalworking. The evidence discussed ranges from the reanalysis of published data to the interpretation of newly generated soil geochemistry. The reanalysis of these existing datasets involved the production of new distribution maps for a range of artefact types in order to interrogate traditional methods of desk-based analysis of metallurgical debris.

Traditional spatial analyses of metal production for the Iron Age have focused on the distribution of production sites, those of iron in particular, across Britain (Paynter 2006, Ehrenreich 1985). In site reports that feature evidence of metallurgical production, there is occasionally mention of the *distribution* of artefacts and debris within the site (*e.g.*, Cleere 1977, Crew 1995, Wainwright 1979), but more often the focus of artefact study has been to elucidate fabrication strategy (McDonnell 1988, Serneels and Perret 2003, Paynter 2006, Girbal 2010, Spratling *et al.* 1980). Artefacts and debris are normally recorded and investigated for insights into the technical specifics of the production processes that resulted in their creation, rather than from a perspective that seeks to understand why particular spaces were chosen and how they were used. Metallurgical production has been identified on sites largely through the presence of scatters of slag as well as other metallurgical debris (Halkon 1995, Wheeler 1943) and in a few cases the discovery of architectural features relating to production (*i.e.*, furnaces and hearths) (Crew 1989, Cleere 1977), with comparatively little or no attention paid to the actual spatial patterning of this evidence of production (with a few notable exceptions *e.g.*, Crew 1988, 2002, Mills and McDonnell 1992). At sites lacking any discernible evidence of primary production, the treatment of metallurgical debris is again predominantly focused on identification of production processes through macroscopic and microscopic analysis of slag and metallurgical ceramics, with even less interest shown for the distribution of those finds, even in light of significant evidence of secondary production at sites such as Gussage All Saints (Wainwright 1979). In spite of the general lack of interest in the intrasite distribution of metallurgical debris, there is still information to be gleaned from its study as will be illustrated through two case studies from the southwest of England.

The three sites treated herein as case studies represent some of the oldest and most extensively excavated sites from Iron Age Britain. The excavations at Glastonbury began in 1892 soon after its discovery under the direction of Arthur Bulleid, later joined by Harold St George Gray, continuing until 1907 (Bulleid and Gray 1911, 1917). The nearby site of Meare was discovered in 1895/6 and excavated from 1910-1933 by the same team as Glastonbury (Bulleid and Gray 1948, Gray and Bulleid 1953, Gray 1966). Maiden Castle is a very long-lived site with foundations in the third millennium BC with occupation, albeit not continuous, extending into the middle of the first millennium AD. The site was investigated through extensive excavation under the direction of Mortimer Wheeler from 1934 until 1937 (Wheeler 1943) and later a much smaller area of the hillfort was excavated under the direction of Niall Sharples from 1985 to 1986 (Sharples 1991).

There are of course many other sites from the Iron Age in Britain that have exhibited significant evidence of metalworking foremost amongst these being Gussage All Saints with its seemingly ‘industrial-scale’ bronze foundry debris excavated by Wainwright in the 1970s (Wainwright 1979, Spratling 1979, Spratling *et al.* 1980, Foster 1980). The evidence of metalworking at Gussage is spectacular in its scale with nearly 600 crucible fragments, more than 7000 mould fragments, and both ferrous and copper-alloy slag and other metallurgical debris recovered. However the nature of the deposition of metalworking debris at Gussage makes it difficult to study from a spatial perspective that is interested in the loci of production as well as deposition. The majority of metallurgical material recovered came from a single pit and the remainder was scattered around the site in other pits and ditches with the actual floor levels missing due to erosion. Though Gussage was remarkable for its complete excavation, the limited contextual data provided by the depositional state of the metallurgical material made it an unsuitable case study for this thesis.

More recently the site of Hartshill Copse in Berkshire excavated by Collard and Darvill has tantalised Iron Age scholars with its evidence of ironworking purporting to date from the tenth century BC (Brett *et al.* 2004, Collard *et al.* 2006), making it the earliest evidence of iron production in Britain. Regardless of the dating of the site or its metalworking, it does present evidence of considerable metallurgy in the Iron Age. Interestingly, the majority of the metallurgical debris recovered from the site is in the form of hammerscale (Collard et al. 2006: 388-398), which in the presence of preserved floor levels could provide a great deal more information as to the specific loci of metalworking practices. However, much like Gussage, Hartshill Copse has suffered greatly from truncation with no floor levels remaining from the occupation of the site. Instead we are left with a great deal of artefacts that present information as to final deposition but can do less to elucidate other stages of production within the settlement.

Even sites that have not been truncated are not always ideally excavated for the study of the spatial aspects of metalworking practice. Broom in Bedfordshire was excavated from 1996 to 2005 by Cambridge Archaeological Unit in advance of development. What was uncovered across the expansive site was a collection of prehistoric activity spanning millennia. The LBA and Iron Age occupation of the site was of particular interest as it uncovered contemporary evidence of both ferrous and copper-alloy metalworking debris in shared contexts. These contexts of the metallurgical finds at Broom were pits and ditches not floor levels, though there is a single mention of the excavators sampling the area surrounding one of these findspots. ‘The soil surrounding this material was tested for hammer-scale and produced an abundance of both spherical pellets and angular plate-like pieces; the remains of both forging and smithing’ (Cooper and Edmonds 2007: 165). The post-ex appraisal (Doonan 2007) of the metalworking debris recovered from the site is nuanced and notes the importance of the discovery of contemporary artefacts related to diverse metallurgical practices (*i.e.*, copper casting and iron forging and smithing). However no assessment of the site’s metallurgical debris post-ex can produce contextual information that was not recovered during excavation. The decision to sample the sediment surrounding a particular cache of metalworking finds was astute, however without continuing such sampling across a wider area or to the regions surrounding other findspots it does little to add to our understanding of the contexts in which metalworking was practiced at Broom and further illustrates the import of liaising with metallurgical experts during the process of excavation.

Both of the Lake Villages (Bulleid and Gray 1911, 1917, 1948, Gray and Bulleid 1953, Gray 1966) as well as Maiden Castle represent excavations that did recover floor levels and have produced datasets with some degree of XY and possibly Z coordinates associated with their finds recordings. Moreover Sharples’ (1991) excavation of Maiden Castle took pains to sample and save sediments from across the site for the purpose of phosphate analysis that were later archived and made available for this thesis to investigate via portable XRF. The issues surrounding the dataset from Glastonbury, and by extension Meare, have been explicated in depth by Coles and Minnitt and others

(Coles and Minnitt 1995, Clarke 1972, Barrett 1987). The greatest limitation in the datasets for Glastonbury and Meare for this reappraisal of the evidence is the frequent lack of information tying metallurgical find spots to their vertical position within the mounds, making relative phasing of material often impossible. Further it is more than likely that a considerable amount of metalworking debris was discarded or ignored due to its size or less conspicuous nature. In particular small crucible or mould fragments as well as very small slag or dross pieces that might commonly be retrieved via sieving were most likely not recovered. In contrast, the dataset from Maiden Castle though over 30 years old presents considerably fewer issues for reappraisal. The vast majority of finds were carefully associated with phased contexts and the sediment samples, collected from across the site as well as within specific contexts of Trench IV, were taken on a grid and logged and stored according those XY coordinates and contexts. It must be noted though that some of the samples examined for this thesis were in fact mislabelled by context but were fortunately still useful due to XY coordinates that spatially distinguished them from other samples. Human errors such as this are always possible regardless of the age of the excavated materials and no more or less likely with modern excavations or even with *in situ* research.

Whilst we can easily critique and criticise the excavation methods utilised by Bulleid and Gray at the end of the 19^{th} and beginning of the 20^{th} centuries, it bears repeating that one simply cannot excavate evidence that does not exist. And in the case of a large number of sites in Southern Britain that have been excavated recently, floor levels are largely absent due to erosion or truncation from later agricultural activities. And even when floor levels remain excavation strategies seldom allow for the sampling of sediments at the resolution necessary for a thorough understanding of the spatial segregation of practices on site. Without intervention by metallurgical specialists during the course of excavation (see Appendix C) the vast majority of contextual information that might be preserved in the soils and sediments is lost and we are restricted to the information to be gleaned from the study of macroscale finds alone.

Using evidence from modern excavations, especially ones currently in progress, was always the ideal of this thesis research. Throughout the course of this thesis' research numerous efforts were made to contact and liaise with local units in the process of excavating Iron Age sites in hopes of locating evidence of metalworking *in situ*. Unfortunately due to the time constraints of doctoral research no suitable excavations were made available. Moreover due to the development rather than research-driven nature of many modern excavations, those Iron Age sites that were investigated recently and that did produce significant evidence of metalworking (*e.g.*, Broom, Rooksdown Hospital) were not sampled in a manner suitable to the purpose of this thesis' inquiry (Cooper and Edmonds 2007, Doonan 2007, Butterworth 1994).

ARTEFACT-BASED METHODS

Glastonbury Lake Village, Somerset

Introduction

Glastonbury Lake Village (EH Monument# 194156, NMR# ST 44 SE 5) located within the Somerset Levels was a waterlogged village dating to the Middle Iron Age through Early Roman period. This site, constructed at the edge of a marshland on timber supported mounds (*i.e.*, crannogs), was exceptionally well preserved when discovered in the late 19th century (Bulleid and Gray 1911). The mounds themselves showed evidence of continual renewal through the laying of successive floor layers upon which considerable metallurgical debris was discovered. The Lake Village consisted of at least 90 mounds, which Bulleid and Gray determined represented dwellings. Over the course of their excavations the pair were ostensibly meticulous in their recording of the position of numerous artefact types as well as the stratigraphy of the mounds themselves. These maps, detailed the locations of a variety of small finds (*e.g.*, stone, iron, copper, crucibles, *etc*.) across a Cartesian grid, based upon distance from a mound centre point in a cardinal direction. However, it later became apparent that material was discarded (notably, mould fragments are absent from the artefactual record). Thus it appears that the excavators did not attempt to understand or interpret the phasing of the long-lived site. In particular, Bulleid and Gray often make mention of the number of floors as well as hearths in a particular mound, yet the vast majority of finds are not referenced to particular floors and instead only linked contextually to the mounds as a whole (Coles and Minnitt 1995). All things considered, Bulleid and Gray excavated, though not superbly, a very complex and inherently difficult site. However, this lack of contextual detail, in terms of find location and mound construction, yields little information in terms regarding how the overall site phasing was linked to the artefactual record.

The unusual character of the site (most akin to central European lake dwellings (Menotti 2004)), with its seemingly myriad habitation mounds as well as its largely complete excavation, has fascinated archaeologists for decades. Clarke, in the 1970s, used the site as the core of his model of the Iron Age in order to explicate how domestic life was structured around multiple dwellings in which activities, as well as genders, were segregated. Clarke was truly pioneering in his acknowledgement of the potential of Glastonbury to elucidate complex issues surrounding spatial relationships. The extent of the excavation, coupled with the time depth of occupation preserved in the mounds, presented a unique opportunity to consider a spatially centred approach to Iron Age settlement. His ideas were novel, but were widely criticised as overly deterministic; and they could not be sustained when later research phased the site and revealed that the clusters of houses, that Clarke was so focused on, seldom in fact were contemporaneous (Barrett 1987). Ultimately, Clarke's work was hampered by his own astute recognition that 'no archaeological study can be better than the reliability of the observations upon which it is based and the assumptions that frame the development of its analysis and interpretation' (1972: 803). Following on from the work of Clarke, as well as the criticism of Barrett, Coles and Minnitt's (1995) successful phasing of the site has provided much need insight into the organization of the settlement over time as well as adding temporal context to the artefactual record.

Artefactual Record

The Iron Age site of Glastonbury Lake Village is a prime example of a site which produced evidence of bronzeworking in the form of numerous crucibles (37 incomplete examples), runlets, dross, and slag (Bulleid and Gray 1911, 1917, Coles and Minnitt 1995). Bulleid and Gray, who excavated the site from 1892-1907, were careful not to speculate on the extent of metallurgical activity represented by the artefactual remains at Glastonbury; however they were certainly aware that their collection of crucibles was unusual and that the vitrified and/or slagged nature of many of those crucibles was indicative of metallurgical use (Bulleid and Gray 1911: 300). Gray in particular, was cautious in discussing the particular activities that might have occurred at Glastonbury (aside from quite astutely remarking 'The crucibles can only have been used for casting small objects and not for the extraction of metal from ore' (Bulleid and Gray 1911: 300)). Instead, he noted that the inhabitants had considerable knowledge of copper-alloy metallurgy, yet the artefact contexts suggested a lack of definitive relation between furnace structures and other metallurgical artefacts (Bulleid and Gray 1911: 303). Aside from a brief discussion of the chemical makeup of the bronze artefacts found on site and the ceramic composition of the crucibles, the metallurgical debris of the site is dealt with quite superficially (yet perhaps adequately for the time). Gray's discussion of the crucible fabrics is actually quite advanced for the time; it points out an intriguing difference in the composition of the crucibles found on site based on their shapes. Triangular crucibles favoured a more typical chaff tempered fireclay whilst it appears the globular and quadrangular varieties tended more towards finer (*i.e.*, less suitable) fabrics. Interestingly, the spatial distribution of the globular and quadrangular crucibles is relatively restricted; they also show no signs of vitrification or slagging, potentially putting their designation as crucibles somewhat in doubt (Bulleid and Gray 1911: 301-302). Thus for the purposes of this discussion they are still treated as crucibles largely due to their discovery in conjunction with one of the three furnaces identified on site. Later discussions and reappraisals of the Glastonbury material have tended to focus on the determination of the metallurgical techniques that produced the resultant debris (Coles and Minnitt 1995). Coles and Minnitt in particular seem most interested in clarifying that the debris is the result of ferrous smithing and non-ferrous melting, rather than looking at the actual extent of activities within the site. In terms of the metallurgical debris they make reference to the work of Howard (1983), who posited that the lack of moulds on site was indicative of off-site copper-alloy metallurgy. However, the fact that the obvious loci of metallurgical activity within Glastonbury were never covered by houses provides more weight to the idea that they were in fact productive sites; Coles and Minnitt (1995: 142) rightly point out that mould fragments could have easily gone undetected by Bulleid and Gray, or even more likely, were discarded as uninteresting. Rather than simply focusing on the technological underpinnings of the debris recovered from past excavations we should be paying greater attention to contextual relationships inherent within. Minnitt gives us a

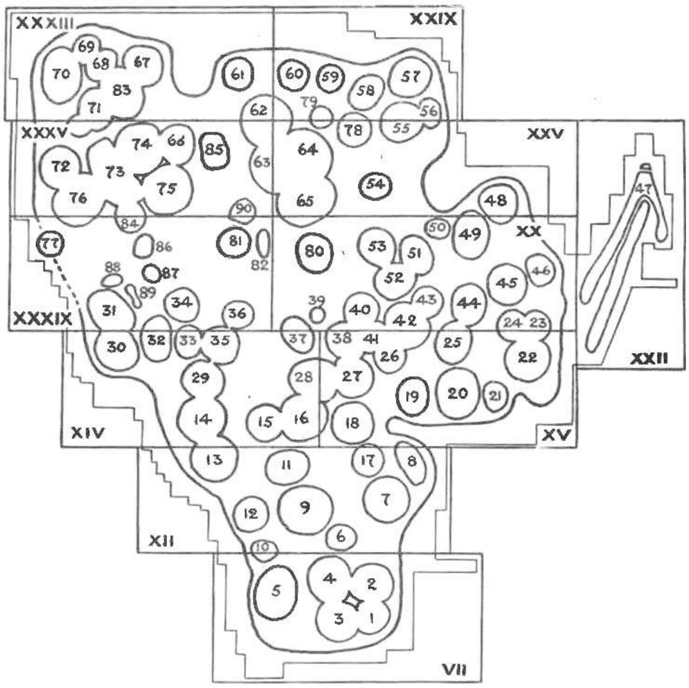


Figure 7.1 Plan of Glastonbury Lake Village (image from Bulleid and Gray 1911: 62), numbers refer to the individual mounds (house platforms) of the site, whilst Roman numerals reference plates in the site report with more detailed area plans.

tantalising hint of this approach when he makes note of the fact that for Mound 5 in the Middle Phase of the site, there is evidence of both copper-alloy and ferrous metallurgy occurring within the same space (Coles and Minnitt 1995: 142). The evidence of production contexts at Glastonbury may not be the most compelling at times, but there is certainly more that can be learned from it through a desk-based analysis of the metallurgical debris.

Analytical Methods

Experimental work can aid in verifying the utility of geochemical and geophysical techniques (see Chapter 6) to establish aspects of spatial organisation in the study of metallurgical production. However useful these techniques might be, they remain limited in how they can be applied to previously excavated contexts unless a sampling strategy was implemented for geochemistry and geophysics at the time of excavation. In light of these shortcomings a more detailed analysis of the metallurgical debris from Glastonbury Lake Village can only proceed at the artefactual level, but by carefully delineating between stratified and unstratified finds in the data presentation, it can still be informative. The excavation reports for Glastonbury Lake Village (Bulleid and Gray 1911) produced in the early part of the twentieth century present a simplified general site map (Figure 7.1) with all excavated mounds numbered. To complement this map, Bulleid and Gray provided painstakingly drawn plans of the individual mounds on the site, as well as all numbered finds, broken down into areas, much like modern road atlases. The latter maps were of great utility for undertaking a spatial analysis of the material from the Glastonbury Lake Village excavations. The originally published plans were digitised and stitched together to produce a high-resolution map of the entirety of the excavated site. When imported into ArcGIS 9 (ArcMap 9.3) and georeferenced to EDINA Digimap Historic National Grid County Series 1:2500 1st edition (1854-1901) tile 31st4940, the base conditions were established for the subsequent population of archaeometallurgical datasets.

By plotting out distributions of artefacts for each of the periods of the site, (*i.e.*, Early, Middle, Late, and Final) as identified by Coles and Minnitt (1995), a phased picture of the metallurgical activity on the site can be produced. For some of the artefacts these phases are not absolute and simply reflect all periods in which a mound was occupied, yet for other stratified artefacts a more accurate picture of Glastonbury through its phases is possible. In light of the lack of more specific contextual information (as is often the case in older excavations) these data cannot present the full picture of patterns on the site over time, yet they can illustrate some general observable trends.

Results

One of the first questions that can be asked of Glastonbury is: are there contexts of metalworking within the settlement? While Bulleid and Gray did not take pains to identify specific contexts of production, they were quite comfortable identifying three furnaces on site. Clarke, in his treatise on a provisional model of the Iron Age, was quick to ascribe not only metalworking activities to ‘major houses’ of the settlement but also to subsidiary workshops where male activities took place (Clarke 1972). Coles and Minnitt in their reappraisal of the site remain equally cautious, content to simply discuss the technical origins of the debris recovered, rather than more situated practices (1995). No author has explicitly stated that the site lacks metalworking contexts, yet they all seemingly have been somewhat reluctant to discuss the bodily practices that inhabit such a context. Archaeometallurgical discussions more commonly rely on chemical equations to describe dehumanised technical processes rather than fully situated human practices (Ehrenreich 1986, Ben-Yosef *et al.* 2010, Heald 2005). From a broad perspective metalworking sites are often divided into those of primary and secondary production (Tylecote 1962, 1986, Craddock 1995). Primary production sites were those wherein metal was won from the parent ores via smelting—a practice occurring either at the ore source or more closely associated with settlements. The products of smelting were then *secondarily* fashioned into objects for consumption through smithing, casting, *etc*. This dichotomous understanding of production is useful when trying to analyse methods utilised by individuals to alter materials as well as to analyse the distribution of particular practices. In their reappraisal of the metallurgical debris, Mortimer and Starley (1993, 1995) have clearly dismissed any notion that smelting occurred at Glastonbury—as Bulleid and Gray were wont to reference any high temperature process that they discovered in the course of their excavations. They were correct to label the metallurgical debris as the result of either ferrous smithing or non-ferrous (largely copper-alloy) melting/casting/smithing. However this categorisation of activities masks an inherent variation in the metallurgical practices that were carried out at sites. And it does little to elucidate the influence these metallurgical endeavours had upon the spaces they existed in, outside of the fleeting instances of creating. By considering these activities as differing classifications rather than events along a continuum, the 'biography of practice' is parsed into discrete yet disconnected spheres. At the site level itself this desire to classify is exemplified by Glastonbury, with only cursory consideration of it as a site of metallurgical interest. The variety of metallurgical debris discovered, and retained, by Bulleid and Gray at Glastonbury is without doubt the *product of production*. The inability to discover an area of the settlement helpfully labelled 'workshop' does not lessen the import of these items. The recovery of at least 37 crucibles both vitrified/slagged and not (*i.e.*, used and un-used), indicates more than the debris of a one-off casting event. Further the presence of cuprous slag, runlets, and dross hints at casting occurring within the settlement. Whilst resources such as copper and bronze ingots would be carefully looked after, little consideration would be paid to the waste of melting down those ingots. The presence of this waste, which has little reason to be transported or curated, lends greater credence to the idea that casting occurred on site. Yet, looking at the excavation over a century later, there is still little one can do to fully reconcile the record of metallurgical debris with the actual practices that produced it.

Without the stratified context of the entire corpus of artefacts, and not just the mounds themselves, a proper phasing of all of the metallurgical artefacts was not possible, even in light of Coles and Minnitt's (1995: 137-143) own reconsideration of metalworking debris. Instead of offering clarity upon past practices, Glastonbury presents a frustrating glimpse of how much information on production in the Iron Age has already been lost.

The distribution of metallurgical artefacts within the site illustrates a settlement where both copper-alloy and ferrous metalworking practices played a role in daily life. The relative proportions of finds suggest that copper-alloy metallurgy was of greater importance to the residents of Glastonbury Lake Village than ferrous. From the Early phase (*sec.* Coles and Minnitt 1995) of Glastonbury it is apparent that there is strong evidence of small scale iron smithing in the northwest of the site occurring alongside potentially rather limited copper-alloy casting largely associated with Mound 75, as well as 74 and 73 (Figure 7.2). Mound 76 also provides evidence of ferrous metallurgy in the form of non-diagnostic iron working slag and smithing hearth bottoms, yet these artefacts are not stratified and are just as likely to be from the later Middle phase as this Early one. Mound 5 at the south of the site, offers the only other stratified metallurgical artefact from the Early phase: a single vitrified/slagged triangular crucible. All other crucibles in the centre and south of the site are also unstratified finds. The Middle phase at Glastonbury presents the most compelling evidence of metallurgical activity within the settlement focused around three different centres each with their own 'furnace'. Beginning in the northwest of the site, there is a continuation of activity on Mounds 73 and 76 as well as unstratified finds from Mounds 71 and 72 (**Error! Reference source ot found.**). The third floor of Mound 76 is home to a possible furnace, most likely a small metallurgical hearth, described by Bulleid and Gray:

> *'The centre of the upper hearth was hollowed out in the shape of a shallow basin with irregular outline. This depression (Fig. 38) was 18ins. in diam., and bordered by a roughly-moulded rim, the depth of which was 2¾ ins., and the width across the base 7ins. The hollow was filled with fire-ash and a few fragments of slag' (Bulleid and Gray 1911: 167).*

Further, the floor itself was 'covered by a layer of fire-ash and charcoal which reached a depth of 6½ ins. in one place; among the ash were several fragments of triangular crucibles, bronze dross, and slag' (Bulleid and Gray 1911: 166). Both used and unused crucibles (*i.e.,* non-vitrified/slagged) were recovered from around this furnace along with copper-alloy slag and ferrous smithing slag, indicative of both metalworking practices occurring within this same space during the same phase of the site's history, if not at the same time. The coetaneous working of copper-alloy and ferrous metals leads to questions about those who worked the metals and if in fact they might be the same practitioners despite the vastly different skills required for the manipulation of the two metals.

At the south of the site on Mound 5 again, is located another furnace in the presence of debris of both ferrous and non-ferrous metallurgy (**Error! Reference source not**

ound.). For Mound 5, Bulleid and Gray (1911: 7) rather ambiguously reference their discovery of 'other remains of a primitive furnace for smelting'. Yet in the context of their subsequent recovery of a tuyère as well as numerous crucibles and other metallurgical debris on the same floor (5) of the mound, the assertion that they found a 'furnace' (or metallurgical hearth) does hold weight. Mound 5 offered up the remains of at least seven triangular crucibles (three of which exhibit signs of use) as well as another unused crucible of the globular variety. Along with the crucibles was some evidence of ferrous working in the form of smithing slag. Though not on the mound proper, there was some copper-alloy slag discovered to the southwest of the mound, potentially discarded from the mound itself. Mound 62 in the north centre of the site represents the final definitive locus of metallurgical activity for the Middle phase of Glastonbury. This mound exhibited another weakly described metallurgical hearth:

> *'from the discovery among the debris of parts of a tuyère, D 30, (see Chap. on Crucibles), and some moulded blocks of baked clay, presumably parts of a primitive furnace, it would appear that smelting had been carried on here' (Bulleid and Gray 1911: 143).*

The metallurgical artefacts discovered on this mound represented the vast majority of the non-triangular variety of crucible: either globular or quadrangular, and most interestingly none of these specimens exhibited any signs of use. The presence of a tuyère along with some copper-alloy slag is suggestive of metallurgical activity but it is curious that all crucibles remain unvitrified on this mound. Further, of the three furnaces this is the only one to show no evidence of ferrous activity in its immediate surroundings, suggesting perhaps a rather more circumscribed practice centred at this mound. A last area of potential interest on the site for this phase is the western part of the settlement which displays evidence of unstratified finds related to copper-alloy metallurgy.

The Late phase (Figure 7.4) at Glastonbury presents a dramatic turn away from the flurry of metallurgical activity exhibited in the previous phase. For both this and the Final phase (Figure 7.5), there is only limited evidence in the form of metallurgical debris on site. For both phases, the most conclusive artefactual evidence comes from the western area of the site in the form of vitrified and/or slagged crucibles, though there is not stratified copper-alloy slag to contextually connect with these finds; nor is there any evidence of specific furnace structures or other metallurgical apparatus such as tuyères. In short, the evidence for these phases is quite thin on the ground and could quite easily be dismissed as the product of curation, rather than any continued metallurgical activity on site.

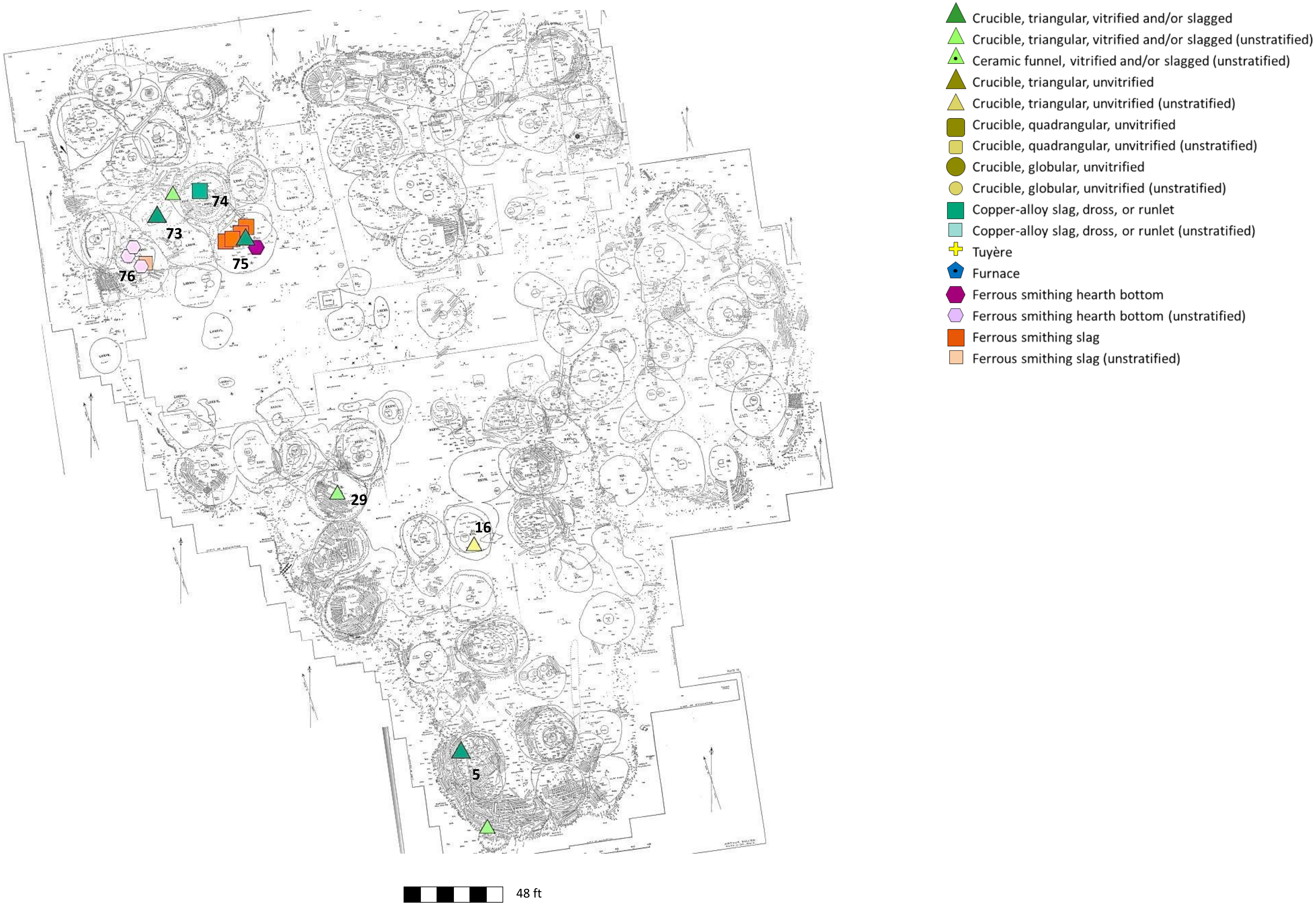


Figure 7.2 Map of metallurgical debris from Early Phase of Glastonbury Lake Village with house platforms of interest labelled (image after Bulleid and Gray 1911).

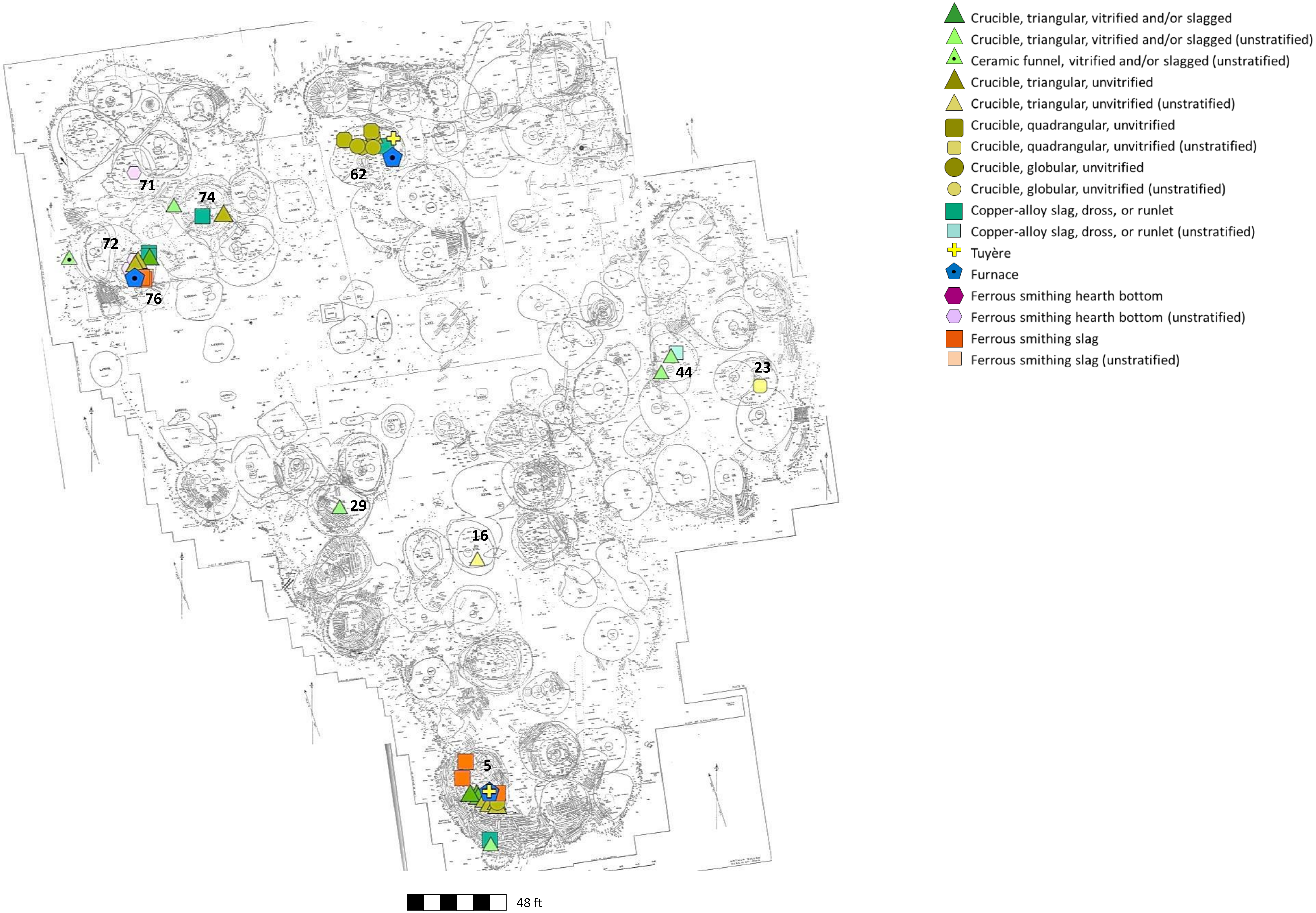


Figure 7.3 Map of metallurgical debris from Middle Phase of Glastonbury Lake Village with house platforms of interest labelled (image after Bulleid and Gray 1911).

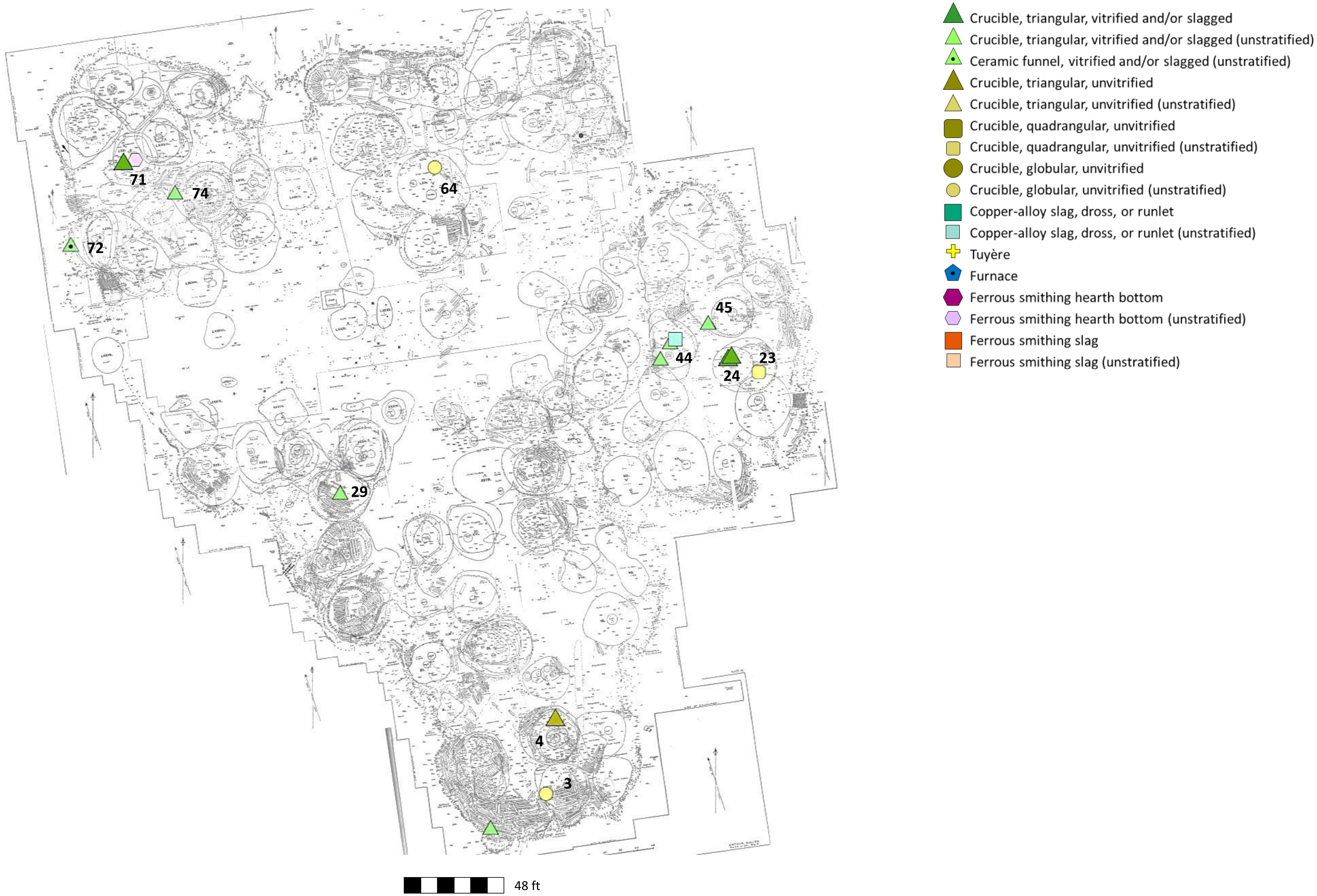


Figure 7.4 Map of metallurgical debris from Late Phase of Glastonbury Lake Village with house platforms of interest labelled (image after Bulleid and Gray 1911).

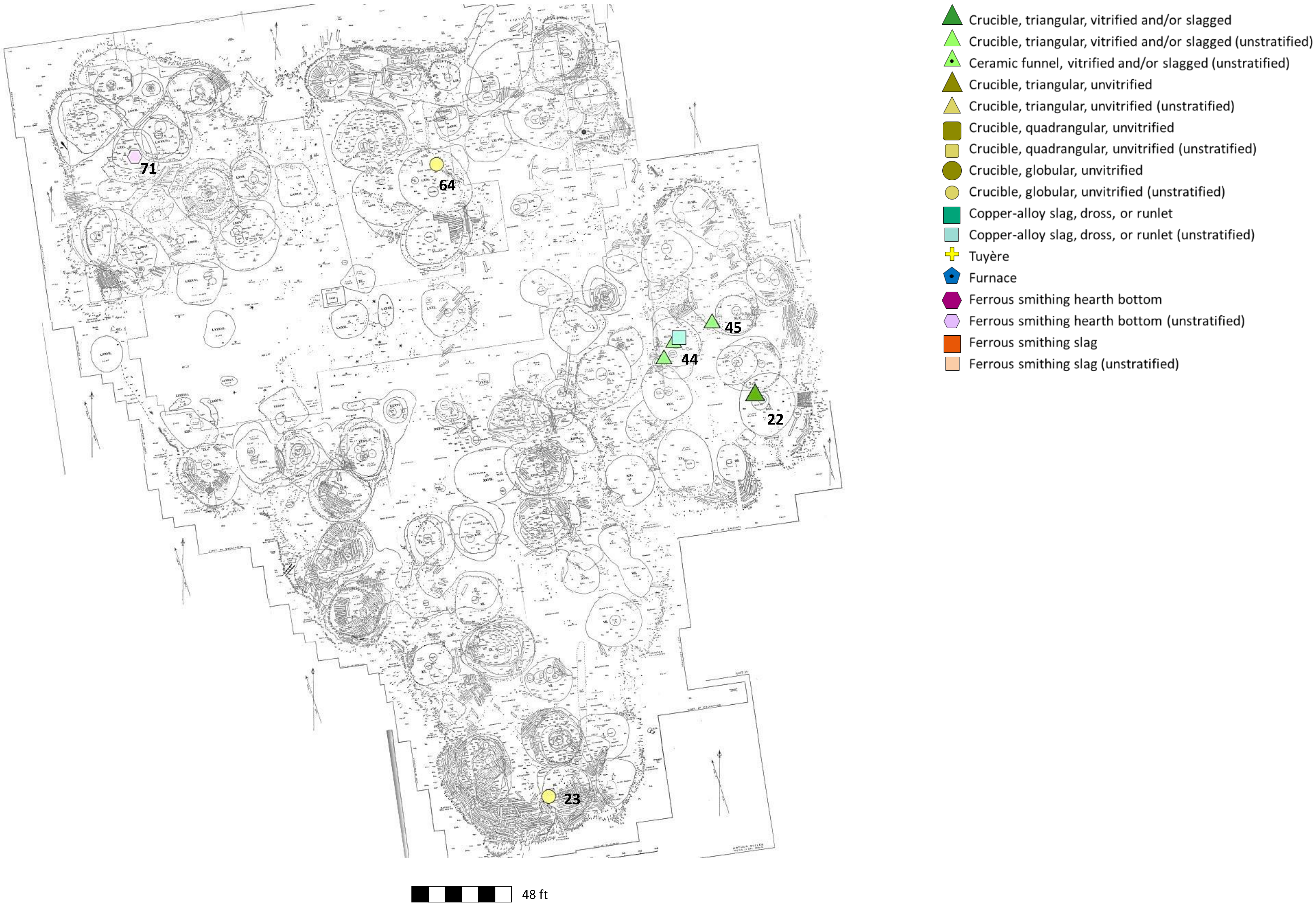


Figure 7.5 Map of metallurgical debris from Final Phase of Glastonbury Lake Village with house platforms of interest labelled (image after Bulleid and Gray 1911).

Meare Lake Village, Somerset

Introduction

The second site examined is the waterlogged settlement of West Village of Meare Lake Villages (EH Monument# 194185, NMR# ST 44 SW), also located in Somerset Levels 4km to the northwest of Glastonbury Lake Village. The site was excavated by the same team of Bulleid and Gray from 1910-1933 (Bulleid and Gray 1948, Gray 1966, Gray and Bulleid 1953). Like Glastonbury, the site of Meare was similarly constructed of numerous crannogs which were repeatedly re-floored to produce deep stratigraphy. As at Glastonbury, finds were meticulously recorded by their relation to mound centre point with little consideration of their vertical placement within the mounds themselves.

Artefactual Record

At Meare, the excavators again uncovered a wealth of metallurgical debris in the form of crucibles (over 40 fragments and complete vessels) and slag (copper-alloy and ferrous). Unlike at Glastonbury, Bulleid and Gray did not explicitly identify any of the hearths within the site as furnaces; though there were a tuyère as well as anvils recovered which aid in indicating centres of metallurgical activity. As for Glastonbury, Gray was responsible for treating the crucibles in the site report, which he viewed as evidence both of the melting and smelting of copper. Inexplicably, he considered that metallurgical evidence recovered from Meare indicated that 'the lake-villagers who used these crucibles were not merely workers in copper; they were smelters' (Bulleid and Gray 1948: 256)256. Whilst some of the crucibles from Meare were considerably larger than those recovered from Glastonbury, this alone, especially in the absence of significant slag, is not sufficient evidence of smelting and further analyses of the metallurgical debris were inconclusive (Doonan 1999).

Analytical Methods

Unlike Glastonbury, Meare has not benefitted from a systematic reappraisal of its excavation. Like Glastonbury's earlier excavation, Bulleid and Gray produced both a simplified plan of the site (Figure 7.6), along with exceedingly detailed plans of all mounds excavated. As before, all originally published plans were digitised and conflated to produce a high-resolution map of the entirety of the excavated site. This base map was then imported into ArcGIS 9 (ArcMap 9.3) and georeferenced to EDINA Digimap Historic National Grid County Series 1:2500 1st edition (1854-1901) tile 31st4441. Metallurgical debris from the site was then plotted on to the site map to produce a single phase distribution of artefacts. Without further phasing for Meare available, only general trends about the distribution of metallurgical artefacts across the site can be commented upon. Overall, the distribution of finds from Meare is much more dispersed with less discernible patterning, most likely compounded by the lack of temporal resolution.

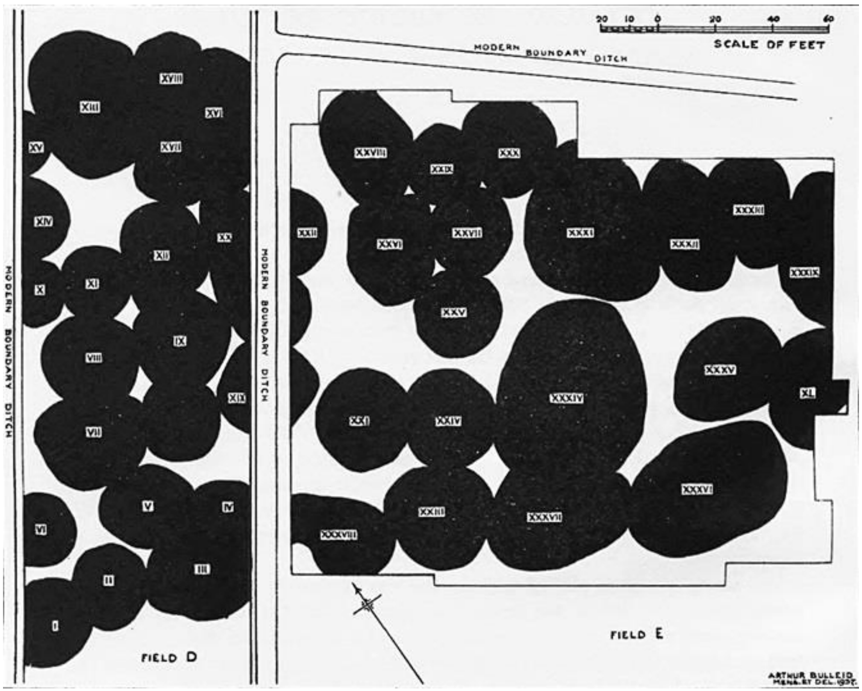


Figure 7.6 Plan of eastern half of West village of Meare Lake Villages (image from Bulleid and Gray 1948: 108). Roman numerals refer to the individual mounds (house platforms) of the site.

Results

The two most likely metallurgical activity areas are to be found to the northwest of the site in Field D, as represented by the find locations of the two anvils—part of the equipment necessary for either copper-alloy or iron smithing. The presence of abundant debris of copper-alloy sheet and rivets is also suggestive of activities focused on sheet working alongside the casting, indicated by the presence of crucibles and runlets. The single tuyère recovered from the site is also located in Field D, though at some distance from the two anvils. However, it is essentially a portable artefact and could have been moved to metallurgical hearths as needed, and thus its find location might have no bearing on where it was in fact utilised. Perhaps most surprisingly there are no particularly evident increases in the density of crucibles, copper-alloy slag or fragments, or ferrous slag around any of these three critical pieces of metallurgical equipment. Overall, copper-alloy activity production debris is more widely distributed than debris associated with ferrous metallurgy.

The range of metallurgical debris recovered from Meare is different from that recovered from Glastonbury. The vast majority of crucibles found at Meare fit into the typical ‘mould’ of triangular Iron Age crucibles, though with some notable size variations and a few globular and quadrangular crucibles within the collection. Whilst more crucibles were vitrified and/or slagged than not, the proportions are still close to equal, and there is not an abundance of copper-alloy slag/dross/runlets to accompany increased evidence of crucible use. The most notable difference between the two Lake Villages in terms of copper-alloy artefacts is the fragments of copper-alloy sheet, rivets, and other fragments which are found across Meare. The second significant difference is in the ferrous metallurgical debris. For Meare, Bulleid and Gray have identified a class of material as ‘worked bloom’. Without actual physical study of such material it is difficult to determine if such artefacts are in fact the result of the first step of consolidation following primary iron production. It is tempting to agree with Bulleid and Gray’s designation, as they have also identified examples of iron ore on site, yet the link still remains tenuous at best without further evidence of pyrotechnological features. Interestingly, these ‘worked blooms’ are not accompanied by smithing hearth bottoms, suggesting that further secondary iron smithing was not a major activity at Meare. This might indicate a link between the two sites, where primary smithing was undertaken at Meare before being transported to Glastonbury to be fashioned into objects. Nonetheless, the evidence for primary smithing is still limited and potentially flawed through collection bias. Whilst the apparent difference in ferrous metallurgical debris between the two sites is intriguing, firm conclusions cannot be made as to whether or not Meare was a site of iron production in the Iron Age.

Looking to the distribution of copper-alloy metallurgical debris at Meare Lake Village, no clear patterns emerge. Crucibles and copper-alloy slag, dross, and/or runlets are well distributed across the site (Figure 7.7). There is some hint of clustering in Field D to the west of the site where there is a greater density of copper-alloy slag/dross/runlets in conjunction with crucibles, both used and un-used. Further, the lack of concrete patterning is at odds with traditional interpretations of metallurgical activities being carried out solely by skilled practitioners (Tylecote 1962, 1986, Childe 1941, Wertime 1964). However, as mentioned previously, Meare remains unphased making any determination of the contemporaneity of metallurgical debris distributions largely impossible. What is evident from the patterning of the debris is that the material was restricted to particular mounds, which may or may not have been active at the same point in time. The picture of an even spread of metalworking debris across Meare, may simply be a consequence of the lack of temporal resolution, rather than evidence of greater import placed on metallurgical activities at Meare versus Glastonbury.

The ferrous metallurgical debris recovered from the site, is similarly distributed in that it is restricted to specific mounds (Figure 7.8). The presence of ten ‘worked blooms’ spread across the settlement is intriguing; whilst generally associated with the spread of ferrous slag, none of the blooms were found within the same mounds as the two anvils. This could simply represent the anvils being recovered in secondary contexts of discard. More modern studies of iron working contexts have begun to pay close attention to the presence of hammerscale for delineating arenas of practice (Mills and McDonnell 1992, Jouttijärvi 2009, Veldhuijzen 2009a, 2009b). Yet, without the original physical contexts we are constrained the inferences we can make based upon the artefacts originally recovered by the excavators in the early 1900s.

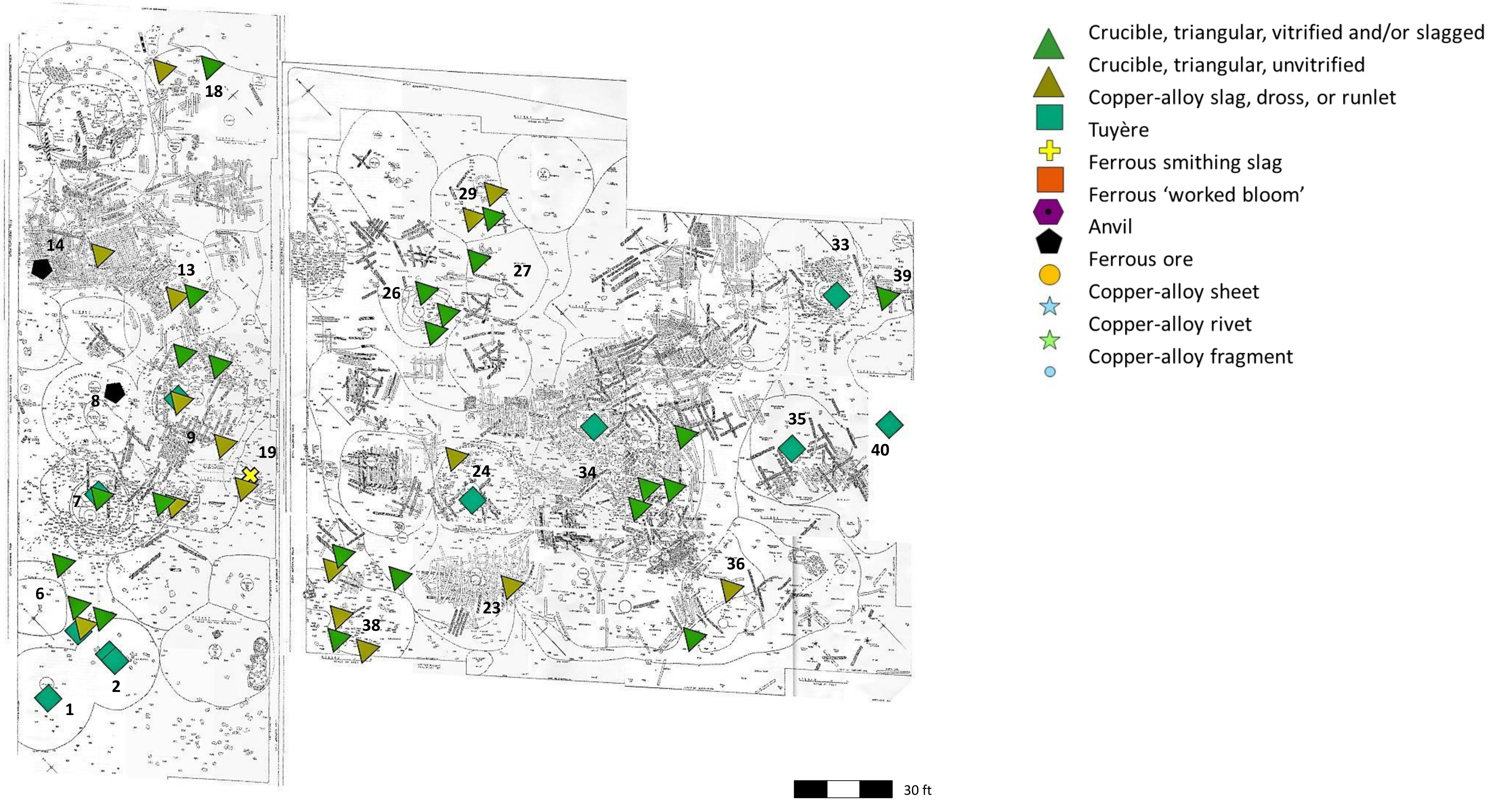


Figure 7.7 Map of copper-alloy metallurgical debris from the eastern half of West village of Meare Lake Villages with house platforms of interest labelled (image after Bulleid and Gray 1948).

Figure 7.8 Map of ferrous metallurgical debris from the eastern half of West village of Meare Lake Villages with house platforms of interest labelled (image after Bulleid and Gray 1948).

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INTEGRATED METHODS

Maiden Castle, Dorset

Maiden Castle is a multi-period site located in West Dorset in south central England, most well-known for the earthwork remains of a multivallate Iron Age hillfort (EH Monument # 451864, NMR# SY 68 NE 7). Extensive excavations have been undertaken at the site twice, first in the 1930s under Mortimer Wheeler (1943) and then from 1985-6 under Niall Sharples (1991). Sharples' excavation in the mid-1980s was revolutionary in its systematic geochemical and geophysical (magnetic susceptibility) analysis of not only the hillfort interior but its environs as well. The geochemical investigations of phosphorous levels in the soil necessitated the taking of samples for wet chemical tests during the post-excavation process. This systematic sampling and subsequent retention, by the Dorset County Museum, of sediments across the site from various occupation contexts presented the opportunity for enhanced geochemical analysis of the excavated contexts of Maiden Castle.

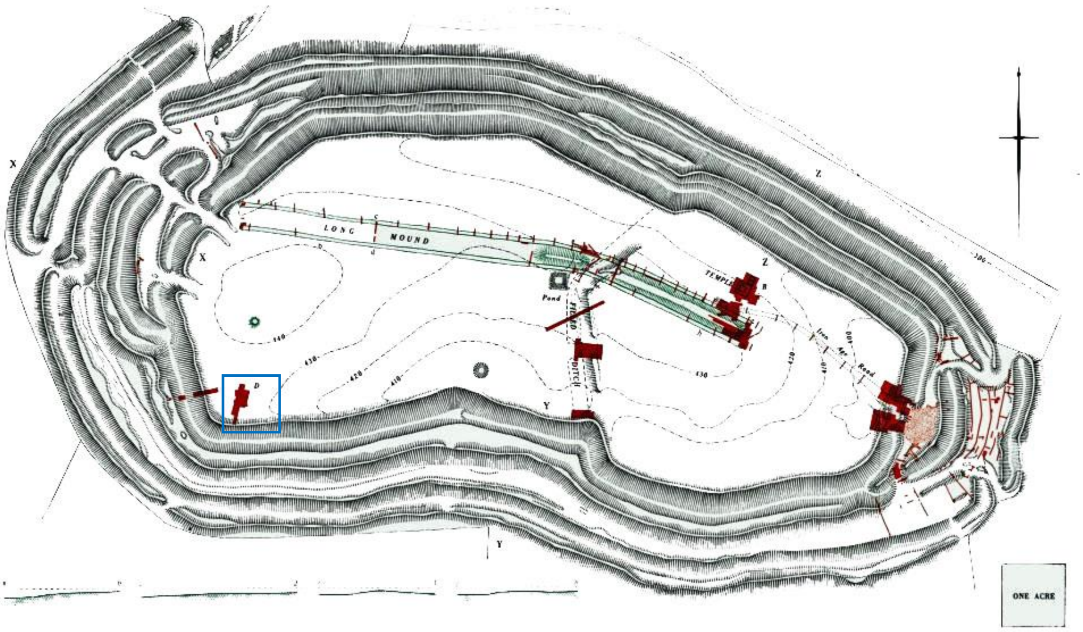

Figure 7.9 Map of Maiden Castle, Dorset highlighting in red the location of areas excavated by Wheeler (1943). The blue box in the southwest corner of the site indicates the location of Wheeler's Trench D and Sharples' Trench IV (1991) (image from RCHME 1970).

Sharples' excavation proceeded with a number of trenches across the site. Here we address Trench IV, in the western portion of the hillfort. Trench IV directly abuts the earlier Trench D of Wheeler's excavation where evidence for metalworking debris was recovered (*i.e.*, evidence of copper-alloy casting and sheet metalwork as well as contemporary ferrous smithing and sheet metalwork (Wheeler 1943, Sharples 1991)) (Figure 7.9 and Figure 7.10). Whilst large scale iron working operations at the eastern entrance to the hillfort are well documented during the Late Iron Age / Roman phase, there is a much lower level of both ferrous and copper-alloy metallurgical activity evidenced from within the hillfort interior during the preceding phase. This activity is specifically concentrated within Trench IV. In light of the well-recorded metallurgical debris from Trench IV, a campaign of geochemical analysis of the archived sediments was undertaken to identify whether the distribution of elements might usefully inform our understanding of metallurgical activities within this earlier phase of occupation at Maiden Castle.

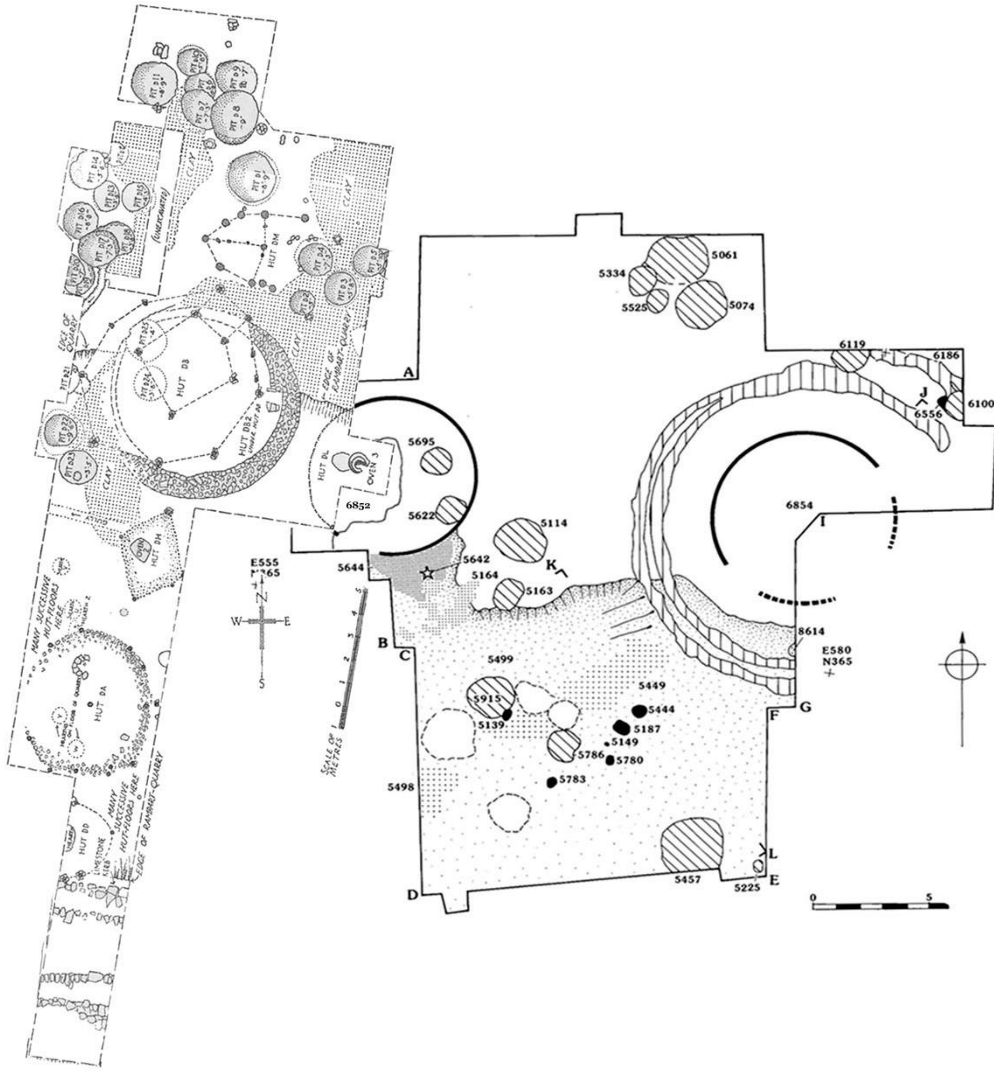

Figure 7.10 Composite plan of Wheeler's Trench D (*left*) and Sharples' Trench IV (*right*) showing the relationship between the two excavated areas (after Wheeler 1943, Sharples 1991).

Artefact-based Analysis

During phases 6E to 6I of Sharples' Trench IV, there is considerable evidence of metalworking. Analyses reported here focus on phases 6F and 6G which have the best documented non-ferrous and ferrous metallurgical debris. The post-excavation treatment of the metallurgical debris was undertaken by two different specialists (non-ferrous and ferrous). The non-ferrous finds were all individually reported and analysed whilst their ferrous counterparts were lumped into classes of material rather than individual finds and reported in a narrative fashion with very little in the way of accompanying tables or discussion of specific distributions. In light of this disparity in the reporting of the debris, a full comparison of the two assemblages is difficult. Instead, the data are reported by contexts and the likely activity from which they derive (*i.e.*, copper-alloy casting, copper-

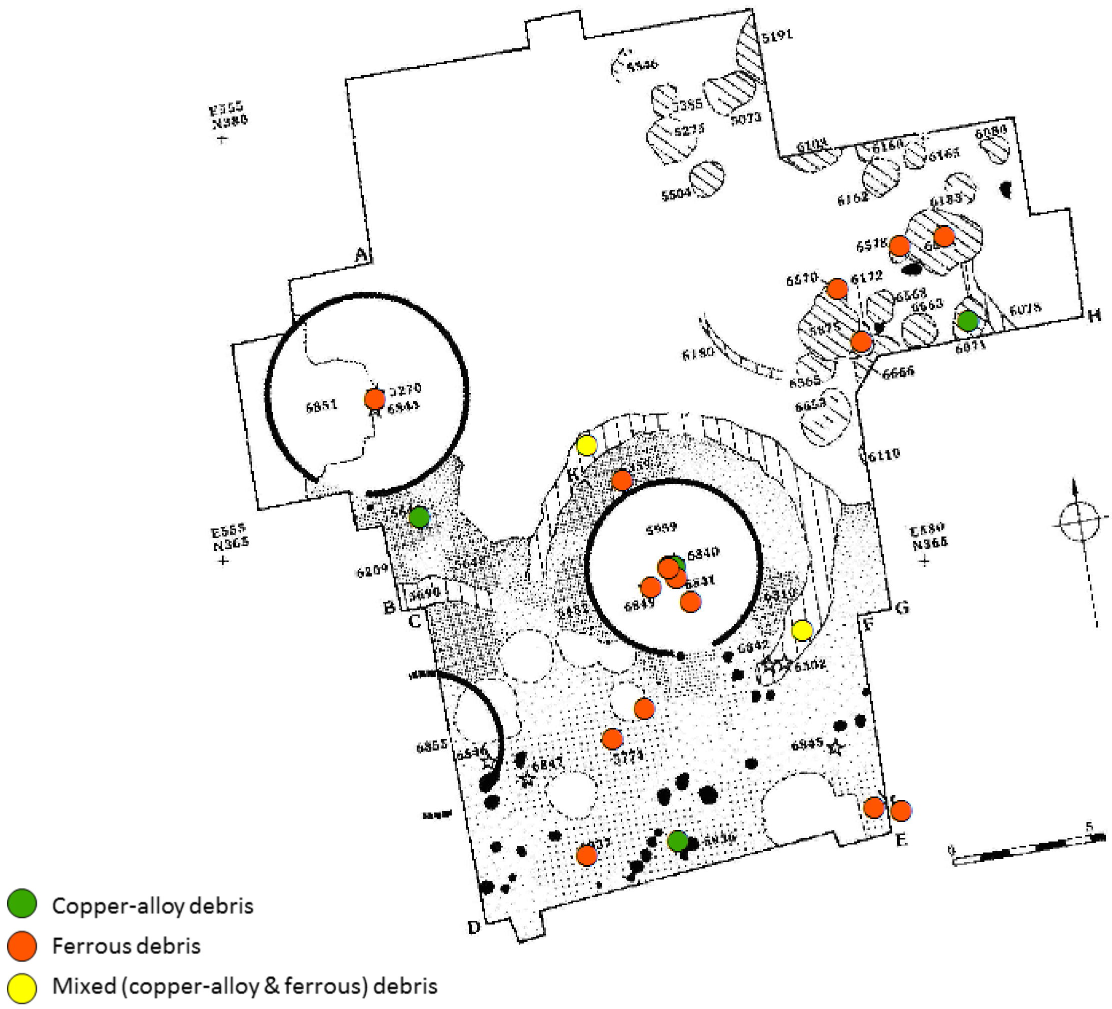

Figure 7.11 Plan of Phase 6F of Trench IV, Maiden Castle, Dorset highlighting the contexts in which metallurgical debris was discovered during the 1985-6 excavations, identified by the type of debris found therein (base image from Sharples 1991: 71).

alloy sheet metalwork, ferrous smithing, and ferrous sheet metalwork). Summary figures present a simplified view of metallurgical activity in the trench, identifying which contexts contained solely copper-alloy or ferrous debris as opposed to those mixed contexts where both were present. In the earlier phase 6F of Trench IV, metallurgical activity is largely focused around the central house as well as the eastern half of the trench, and is predominantly ferrous in nature (Figure 7.11). There are only two explicitly mixed contexts containing both copper-alloy and ferrous debris, but the interior of the central house presents contexts that are either copper-alloy or ferrous in very close proximity. All of the ferrous debris for this phase is the result of smithing rather than sheet metalwork (Figure 7.12). Salter's report on the ferrous debris indicates that the slag from this phase is most likely the product of small-scale secondary smithing and the central house in particular was potentially home to a hearth for these activities (Salter 1991: M8:E8-

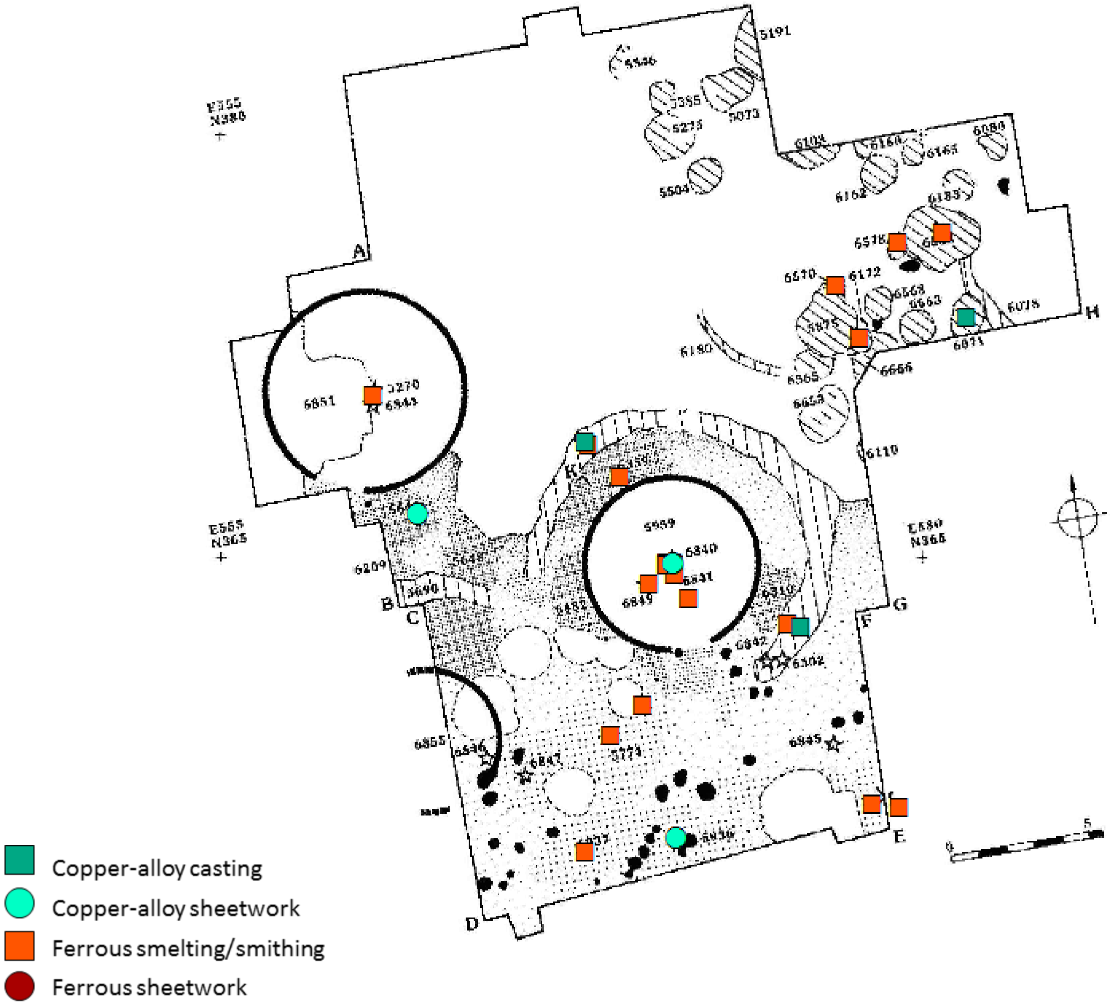

Figure 7.12 Plan of Phase 6F of Trench IV, Maiden Castle, Dorset highlighting the type of metallurgical debris discovered in the contexts identified in Figure 7.11 (base image from Sharples 1991: 71).

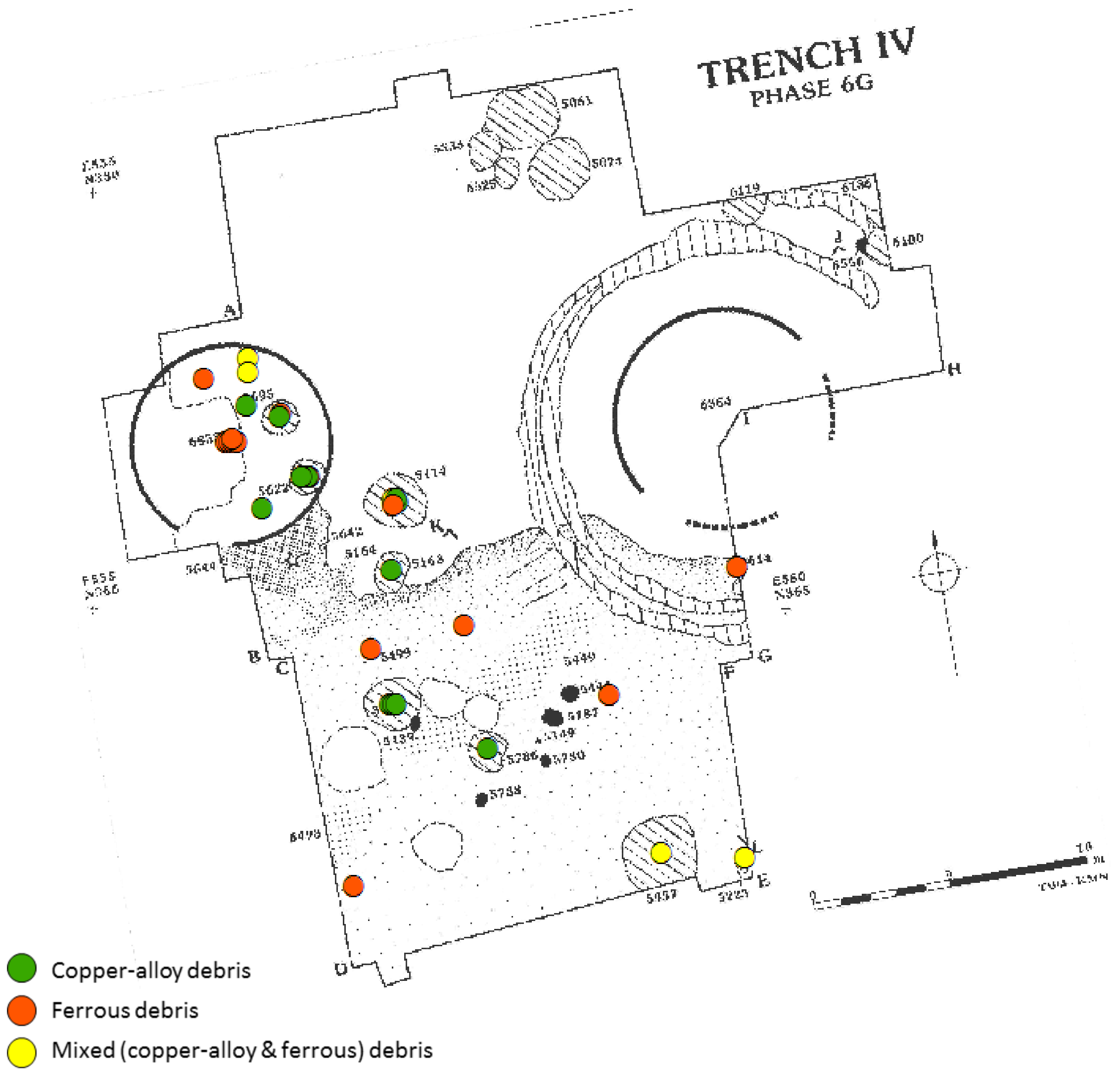

Figure 7.13 Plan of Phase 6G of Trench IV, Maiden Castle, Dorset highlighting the contexts in which metallurgical debris was discovered during the 1985-6 excavations, identified by the type of debris found therein (base image from Sharples 1991: 73).

M8:E9). The copper-alloy debris is quite sparse, though it is notable that the two mixed contexts involved evidence of copper-alloy casting and ferrous smithing.

The next phase presents a marked change in metallurgical practice. Ferrous debris no longer predominates, replaced largely by copper-alloy debris with activity focused upon the western half of the trench and in the western house in particular (Figure 7.13). In phase 6G there are more contexts with evidence of mixed copper-alloy and ferrous debris. The overall picture of activity in this phase is much more diverse and mixed, with evidence of copper-alloy casting and sheet metalwork as well as ferrous smithing and sheet metalwork often located in close proximity (Figure 7.14). Coupled with the evidence of metallurgical debris from Wheeler's Trench D (Wheeler 1943: 94-96, 228, 377-378), which included three crucibles, a bronze runlet, and a quantity of unspecified

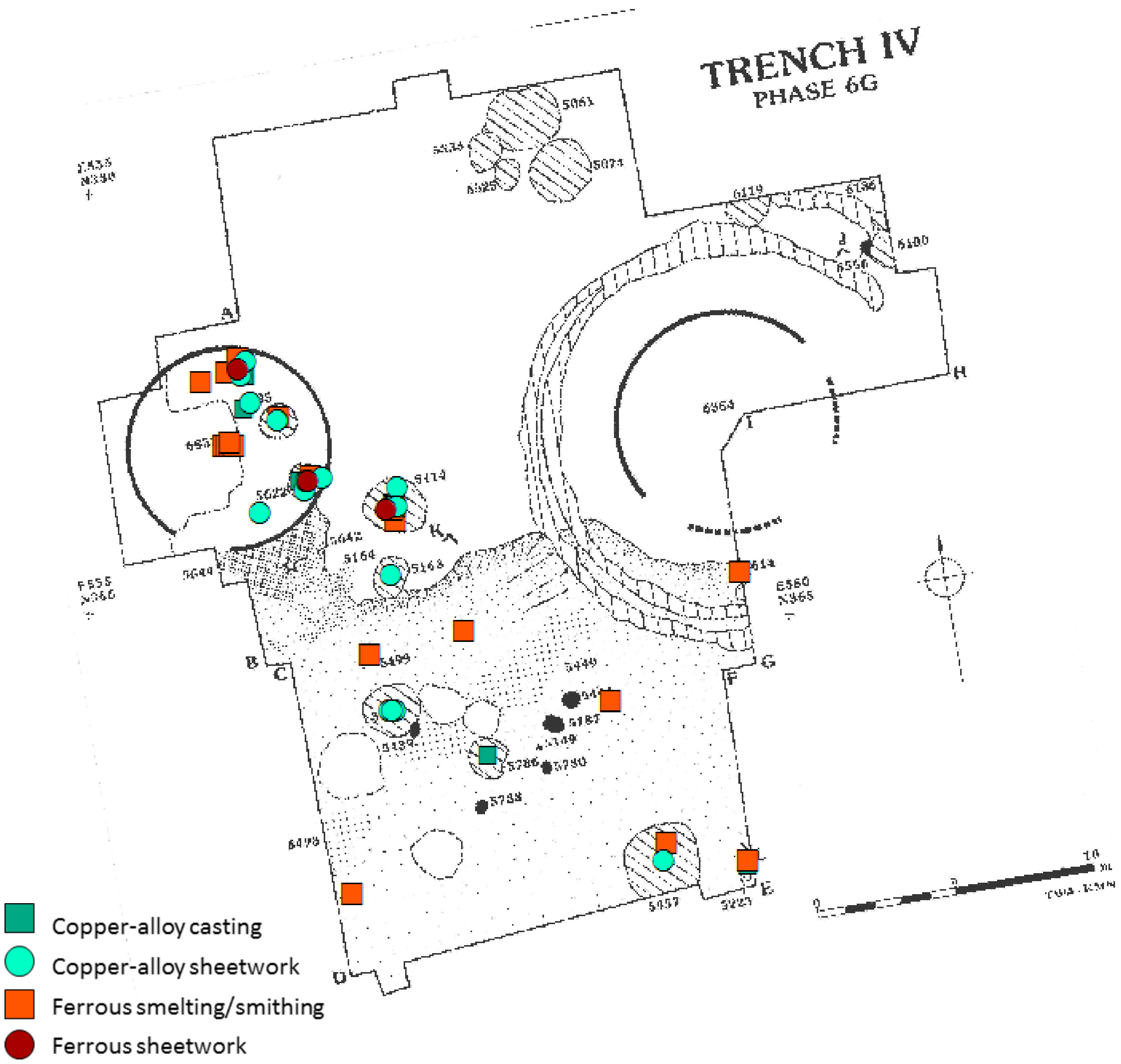

Figure 7.14 Plan of Phase 6G of Trench IV, Maiden Castle, Dorset highlighting the type of metallurgical debris discovered in the contexts identified in Figure 7.13 (base image from Sharples 1991: 73)

slag in conjunction with a variety of ovens of indeterminate purpose in the area of huts DH and DB2 (Figure 7.10), it seems plausible that the area encompassed by these two trenches was in fact a small metalworking quarter prior to the large scale iron smelting efforts of phase 7 in the eastern entrance.

Integrative Analysis

The artefactual data from Maiden Castle presents a picture of limited small-scale ferrous and non-ferrous metalworking occurring within or near to occupation contexts. Artefact data highlight the presence of these activities in the area but they do not locate it in specific space.

The sediments collected in 1985-6 and subjected to magnetic susceptibility and phosphate analysis provide further information regarding the activities in this area of the site. Those data have been re-plotted and interpreted alongside the new geochemical data from the pXRF analysis of the samples.

Sampling Strategy

Samples 16503 and 16504 (*N.B.*, a 'sample' is in fact a collection of upwards of 100 individual samples taken at 0.5x0.5m intervals) covered two layers (6853 and 6852) thought to be different floor levels from within the Western house in Trench IV (Table 7.1, Figure 7.15). In addition the analysis included sample 16506 which came from occupation layer 6854 of the Central House in Trench IV. Due to some confusion in the storage of sample 16506, only a portion of this sample was analysed. Samples 16505 and 16506 were intermixed in storage and a portion of both were analysed. Interestingly, sample 16505 turns out to be earlier floor layer 6851 of the Western House not fully referenced in the site publications.

Phase	Context/ Floor layer	Sample
6G	6853	16503
6G	6852	16504
6F	6851	16505

Table 7.1 Phases of Sharples' Trench IV discussed with corresponding context numbers representing floor layers of the Western House as well as the sample numbers assigned to the sediment samples taken from those contexts for phosphate analysis.

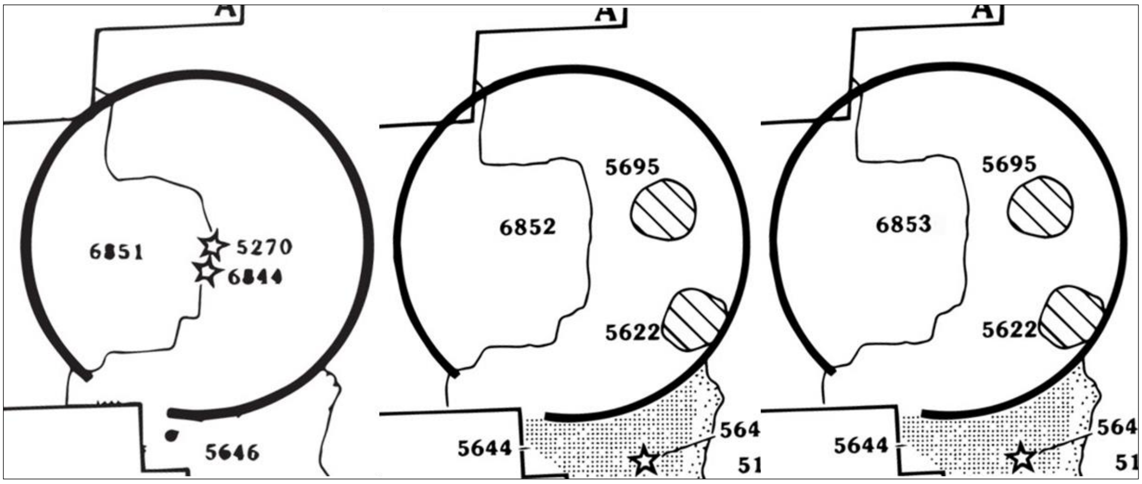

Figure 7.15 Plans of the Western House, Trench IV, Maiden Castle (images from Sharples 1991: 71 & 73).

Methodology

Samples were prepared by sieving through a 750µm mesh and placed in a sample pot covered with a 4µm proline window in readiness for analysis. Analysis was undertaken using a Niton XLT3 HH-PXRF. For the analyses reported here the instrument was used as a bench-top instrument. Analyses were undertaken in standard 'Soil mode' using an analysis time of 45 seconds. Only main filter was employed for analysis. Calibration and standard checks were undertaken routinely throughout the survey to monitor drift and contamination (standards used: TILL-4, GBW07411, NCS DS 73308, and Silica-Blank). The geochemical analysis measured a suite of elements which included Cu, Zn, Pb, Mo, Zr, Sr, U, Rb, Th, Se, As, Hg, W, Ni, Co, Fe, and Mn. Many elements were below detection limits and only Cu, Zn, Pb, Sr, Fe, and Mn as well as P and magnetic susceptibility, from the Sharples' excavation's analyses, were plotted and discussed in detail.

Results

The results of the geochemical analysis, reported in ppm, are discussed below for those elements with greatest interpretative value (see Appendix B for other data). Magnetic susceptibility and P were not measured as part of the reappraisal of soil samples and there were no data for magnetic susceptibility or P from the earliest floor layer (*i.e.*, Sample 16505) of the Western House, these data however are reported alongside the pXRF results. Images are presented of the raw data for all elements and magnetic susceptibility plotted against the minimum and maximum values across all samples for a particular feature so as to provide inter-sample comparability of results. A second set of bubble plots were created based on the z-scores of the elemental and magnetic susceptibility data in order to better highlight intra-sample variation. Z-scores represent a method of standardising or normalising results by calculating a raw value's distance from the mean in terms of the standard deviation. These scores are calculated by subtracting the mean of the population (*i.e.*, the soil sample set) from the raw value and dividing it all by the standard deviation of the population (*i.e.*, $z = \frac{x-\mu}{\sigma}$).

Prior to discussing any particular elements there is a distinct geological anomaly that was detected in the geochemical reappraisal of the samples from the Western House that needs to be addressed (Figure 7.16). This 'feature' which is only present in the earliest layer of the house (*i.e.*, 6851, sample 16505) was first noticed in the data for Sr, when plotting

	16505				16504				16503			
	Mean	**Min**	**Max**	**Std Dev**	**Mean**	**Min**	**Max**	**Std Dev**	**Mean**	**Min**	**Max**	**Std Dev**
Cu	191	149	287	24	192	149	371	25	250	197	413	26
Zn	254	104	563	63	264	155	344	31	267	170	343	27
Pb	22	7	47	7	23	12	38	5	25	16	39	5
Sr	324	136	783	145	284	43	575	76	264	65	469	64
Fe	20104	6122	32320	6304	20776	8913	34496	3475	20812	12124	36055	3082
Mn	2409	669	4893	838	2515	1205	4774	441	2460	1303	4599	375
P	-	-	-	-	5758	2691	9301	1070	5584	4184	10140	792
MagSus	-	-	-	-	231	21	433	84	272	84	455	71

Table 7.2 Basic descriptive statistics for pXRF analytical results from Western House, Trench IV, Maiden Castle alongside previously published data from the P and magnetic susceptibility analyses.

revealed a semi-circular area of enhancement in the northeast quadrant of the house. The greatly elevated levels of Sr here along with the well-defined nature of the anomaly led to further investigation. Upon looking at notes from the pXRF analysis of the samples it was found that these high levels of strontium were detected in conjunction with samples that were recorded as being predominantly chalk. Chalk which is predominantly calcium carbonate ($CaCO_3$) contains high levels of Sr as it is known to be strongly correlated with Ca (Salminen *et al.* 2005: 347). Though the semi-circular nature of the anomaly is intriguing, without samples taken from the interior of the Trench IV (*i.e.*, outside of the house structures) it is difficult to continue an investigation. The presence of excessive chalk in the samples suggests a geogenic origin especially in light of no evidence for plastering of Iron Age domestic structures at Maiden Castle, which could have produced a similarly patterned anomaly.

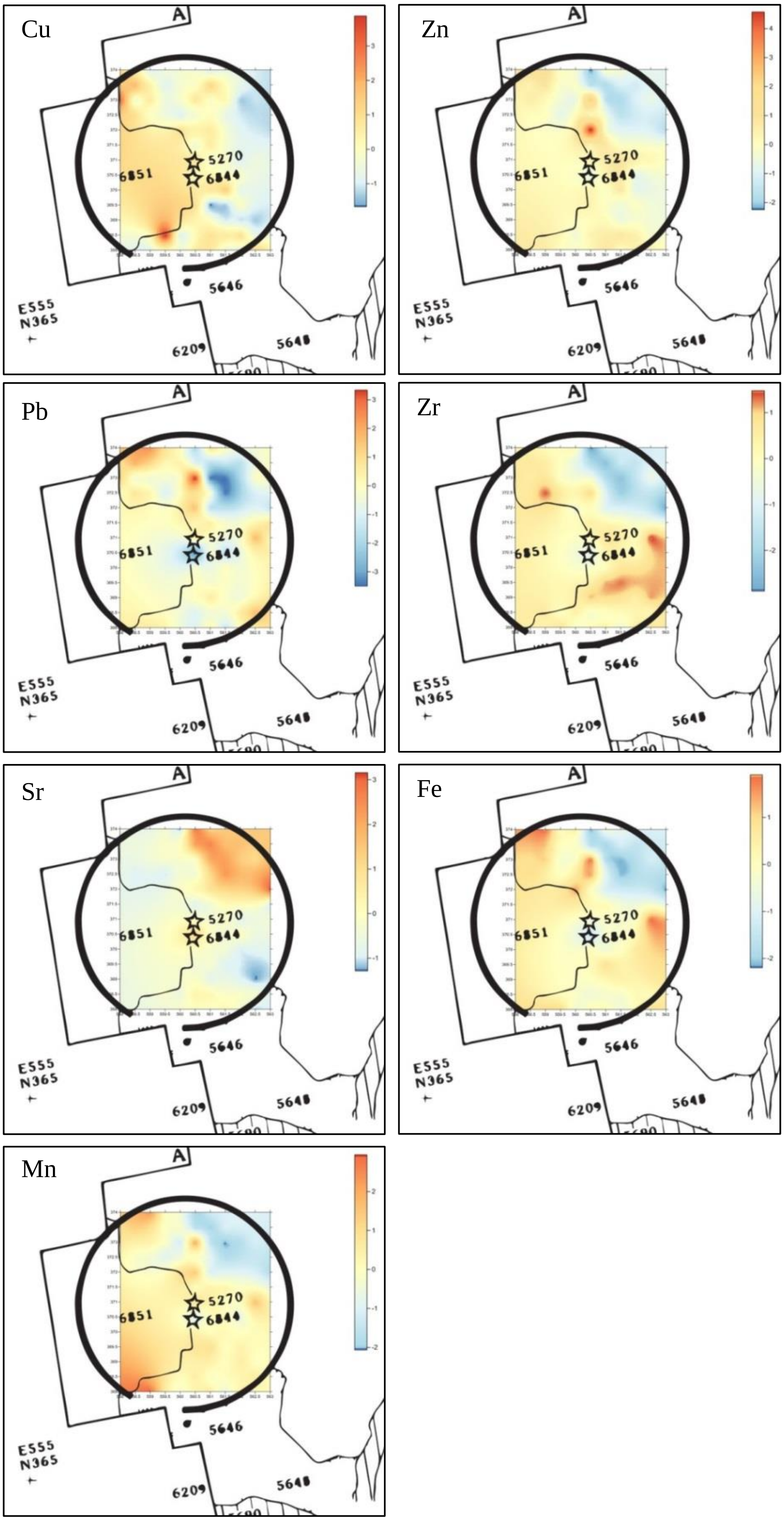

Figure 7.16 Rasters of z-scores for elemental concentrations in the Western House, Trench IV, Maiden Castle in Phase 6F (Floor 6851, Sample 16505) (base image Sharples 1991: 71). Interpolated images produced via ordinary kriging utilising Surfer 11.6.1159.

COPPER

The pXRF results, most notably, reveal an increase in Cu levels from the earliest to latest contexts of the Western House in Trench IV (*i.e.*, 16505 to 16503) (Table 7.2, Figure 7.17). The concentrations of Cu range from 149-287ppm in the earliest phase of the house, increasing to 149-371ppm and 197-413ppm in the latter phase. This upward trend in Cu levels is well-correlated with the increase in copper-alloy metallurgical debris recovered from Trench IV during phase 6G of the site (Figure 7.13 and Figure 7.14).

The variation of Cu levels within the individual floor layers suggests a structured distribution through space that implies it is a result of activities undertaken in that space. Across all layers, Cu anomalies can be seen to shift location within the house. In the earliest layer (6851) from phase 6F, the area of greatest relative Cu concentration is observed in the southwest corner near the door of the structure as well as the northwest near to where the house abuts Wheeler's Trench 4 (Figure 7.10). In the later floor level of phase 6G, there is an anomaly detected north of the centre of the house, which is not well associated with copper-alloy debris. However, an anomaly is also exhibited in the southeast of the house, associated in both floor layers with the area of pit 5622 (Figure 7.15 and Figure 7.17), which produced considerable evidence of copper-alloy slag, copper-alloy sheet fragments, ferrous fuel ash slag, and iron sheet fragments (Figure 7.14).

Over the period of occupation of the Western House, correlations between Cu and other elements as well as the geophysical data are minor. Only Zn exhibited any sort of positive correlation with the Cu concentrations, presenting a correlation coefficient of only r=0.26 for the earliest level of the house.

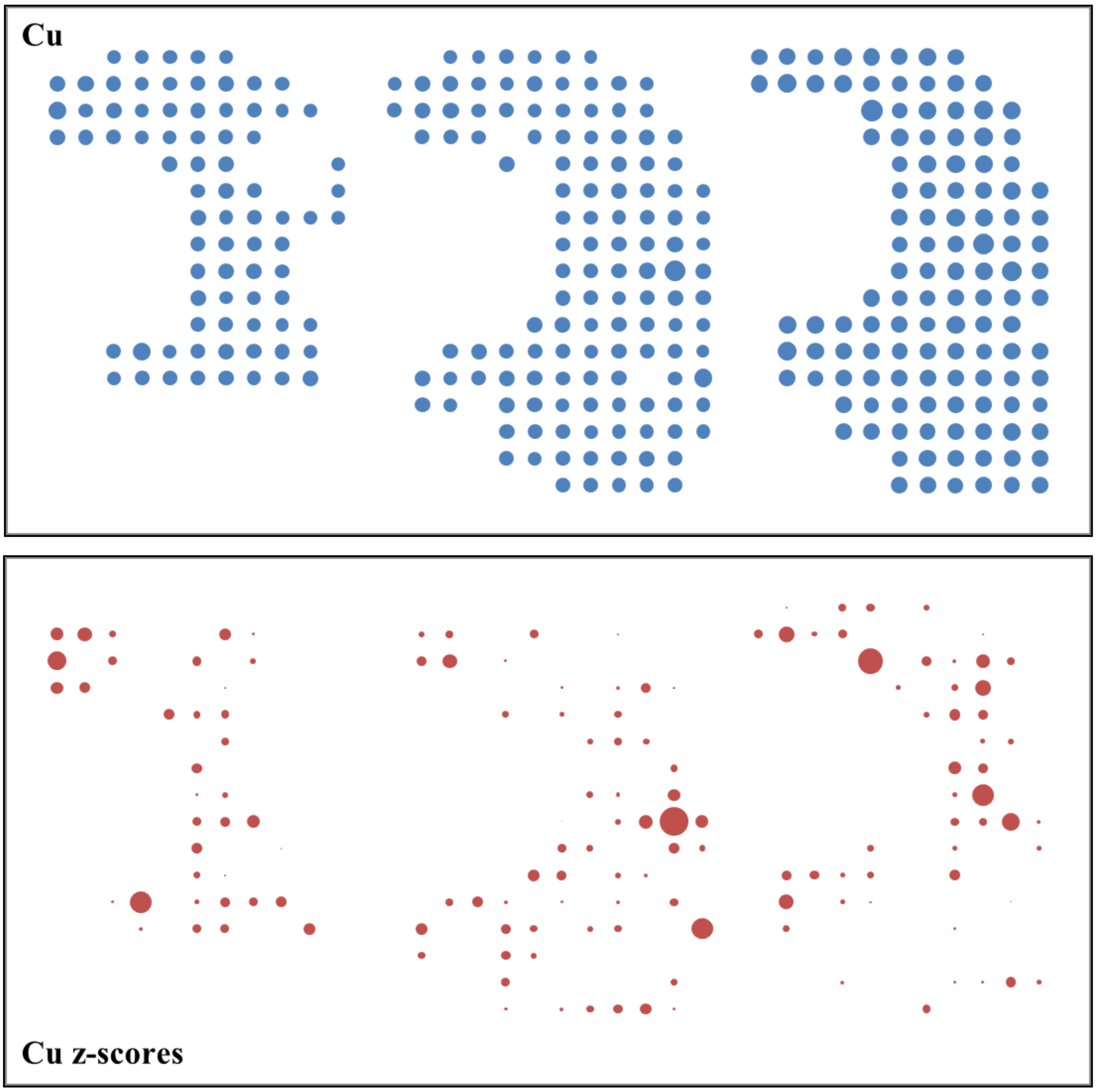

Figure 7.17 Bubble plots of (*top*) Cu concentrations (ppm) and (*bottom*) Cu z-scores in the Western House, Trench IV, Maiden Castle. *From left to right*: Floor 6851/Sample 16505; Floor 6852/Sample 16504; and Floor 6853/Sample 16503.

ZINC

Zinc was one of the elements measured by the pXRF which appeared to decrease over time, though not considerably and likely within instrumental precision. However, what is most conspicuous in terms of Zn concentrations are the two anomalies north of the centre of the house visible in the data from phase 6F, which represent the highest concentrations (419ppm and 563ppm) recorded for the element across all phases of the house (Figure 7.18). These particular anomalies do not persist and are seemingly uncorrelated with Cu concentrations for the same floor level, however they are associated with two Pb, Fe, and Mn anomalies (Figure 7.18, Figure 7.20, and Figure 7.22) detected in the same sample from the Western House. Further, the copper-alloy metallurgical debris discovered from phase 6F did not have high Pb, Zn, or Fe content (*i.e.*, Pb <0.5%, Fe <0.1%, and Zn <0.05%; *N.B.*, Mn was not reported), further all three elements were negatively correlated with Cu (Northover 1991: M8:B7-M8:B8), making copper-alloy debris an exceptionally unlikely source of the anomaly. It is intriguing to find these four elements associated in a set of anomalies and also statistically well-correlated for the entire sample set (*i.e.*, for Zn: Pb r=0.67, Fe r=0.61, and Mn r=0.75).

In phase 6G the aforementioned anomalies are no longer present and the patterning of Zn concentrations (Figure 7.18) is quite different. For floor layer 6852 there appears to be an area of higher Zn concentrations to the northern interior of the house almost directly opposite the entrance to the structure. In the final sample (*i.e.*, floor layer 6853) the z-score plot suggests a preference for the edges of the southern and eastern edges of the structure as well as the doorway. Such patterning is potentially indicative of cleaning behaviour that leads to lower concentrations of elements at the centre of the house with sediment being collected against the walls and just outside of the house. With no obvious source of Zn within the artefactual record, based upon the low levels of the element in the copper-alloy debris, as well as no corresponding increases in the specific contexts (*i.e.*, the pits, Figure 7.14) where much copper-alloy metallurgical debris was found, it is unclear what contributing factor lead to the changes in the distribution of the metal within the interior of the house.

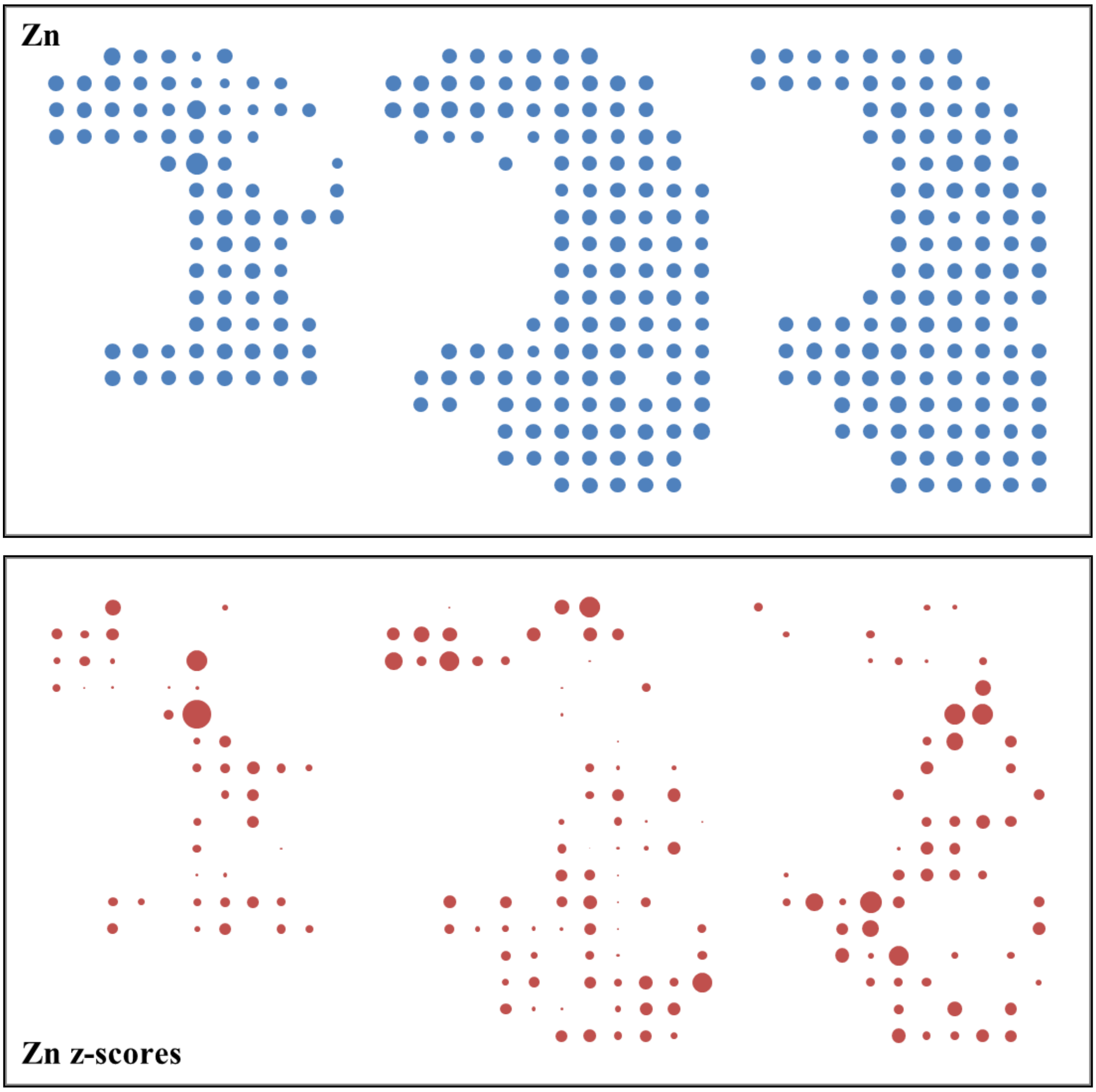

Figure 7.18 Bubble plots of (*top*) Zn concentrations (ppm) and (*bottom*) Zn z-scores in the Western House, Trench IV, Maiden Castle. *From left to right*: Floor 6851/Sample 16505; Floor 6852/Sample 16504; and Floor 6853/Sample 16503.

LEAD

Lead was not detected in high levels (*i.e.*, range of 7-47ppm, Table 7.2) within the Western House, nor did it demonstrate much change in concentrations over time. The Pb concentrations from the earliest layer were well-correlated with those of Zn (r=0.67), and as mentioned previously also exhibited two anomalies in the northern half of the house (Figure 7.19). These seemingly anomalous Pb readings are also very well-correlated with two Zn, Fe, and Mn anomalies (*i.e.*, Zn r=0.67, Fe r=0.78, and Mn r=0.72) detected in the same sample (Figure 7.18), leading one to consider if they are derived from the same parent material.

In the later phase of the Western House, Pb exhibits rather diffuse patterning as demonstrated in the plots of z-scores. In the floor layer 6853 there is potentially an area of increased concentration against the south-eastern interior of the structure, possibly the result of an accumulation of sediments against the wall through cleaning of the interior. Lead concentrations, again like Zn, were not enhanced in the specific contexts where copper-alloy metallurgical debris was recovered (*i.e.*, phase 6G pits, Figure 7.14), nor were they ever particularly high.

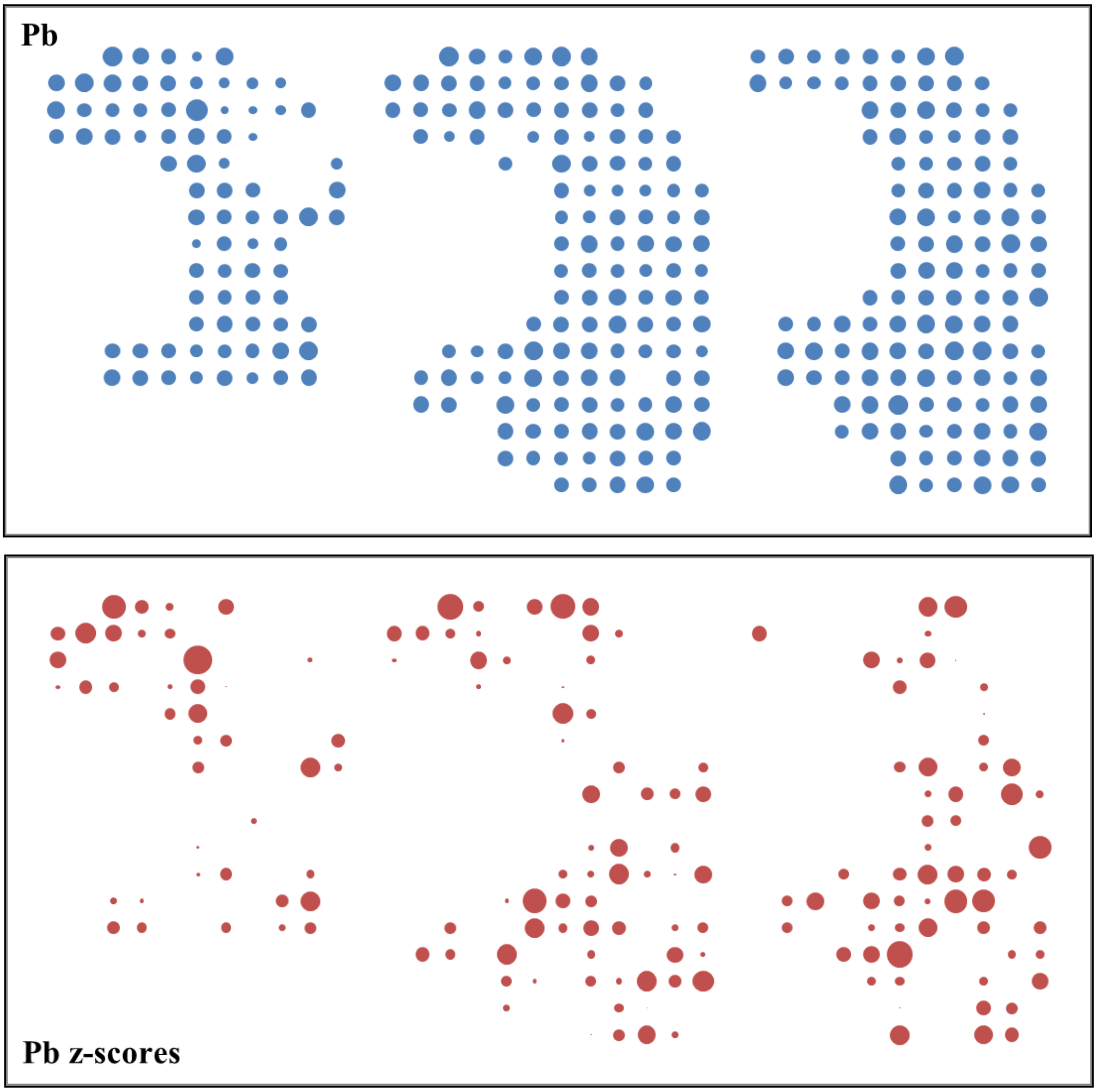

Figure 7.19 Bubble plots of (*top*) Pb concentrations (ppm) and (*bottom*) Pb z-scores in the Western House, Trench IV, Maiden Castle. *From left to right*: Floor 6851/Sample 16505; Floor 6852/Sample 16504; and Floor 6853/Sample 16503.

IRON

The analysis of Fe from the Western House did not reveal high underlying baseline concentrations (*i.e.*, approximately 20000ppm, Table 7.2) nor did Fe levels change perceptibly over time. There is however, a picture of changing foci for increased Fe concentrations across the layers (Figure 7.20) illustrated in the z-score plots. In floor layer 6851, Fe levels appear elevated in multiple spots to the north, including a point well correlated with the Zn, Pb, and Mn (*i.e.*, Zn r=0.61, Pb r=0.78, and Mn r=0.82) anomalies in the same layer, which are not associated with any of the recovered ferrous debris (Figure 7.12). In the next layer, floor 6852, Fe concentrations are generally well distributed with a few points of highest concentration occurring just at the edge of the sample against the interior wall of the structure. The latest layer of the house exhibits an odd vertical alignment of Fe concentration anomalies in the centre of the structure. In an effort to better understand these data, the results for iron for sample 16503 were compared to those for magnetic susceptibility carried out in 1985-6. Intriguingly a similar anomaly is visible in the results, yet instead of an area of elevated enhancement, it is representative of an area of extremely low magnetic susceptibility (Figure 7.24). Close scrutiny of the plans for floor 6853 revealed that the Fe and magnetic susceptibility anomaly closely aligned with one particular context (5313) identified as a clay layer (Figure 7.21), suggesting that the high-Fe low-magnetic susceptibility reading was based on a Fe-rich clay layer rather than evidence of metallurgical or even high-temperature activity. In both layers 6852 and 6853 there appears to be an area of low iron ringing the centre of the structure followed by a semicircle of increased iron (Figure 7.20). This patterning is perhaps indicative of cleaning—material rich in Fe has been moved to the internal peripheries of the house and allowed to accumulate against the structure walls. More interestingly for layer 6853, the data reveal an increased level of iron near the door to the structure and in the area just outside. Whilst the data for Fe demonstrated clear patterns within the structure, overall, the data for Fe are not good predictors of ferrous metallurgical debris or any metallurgical activities that may have occurred in the house.

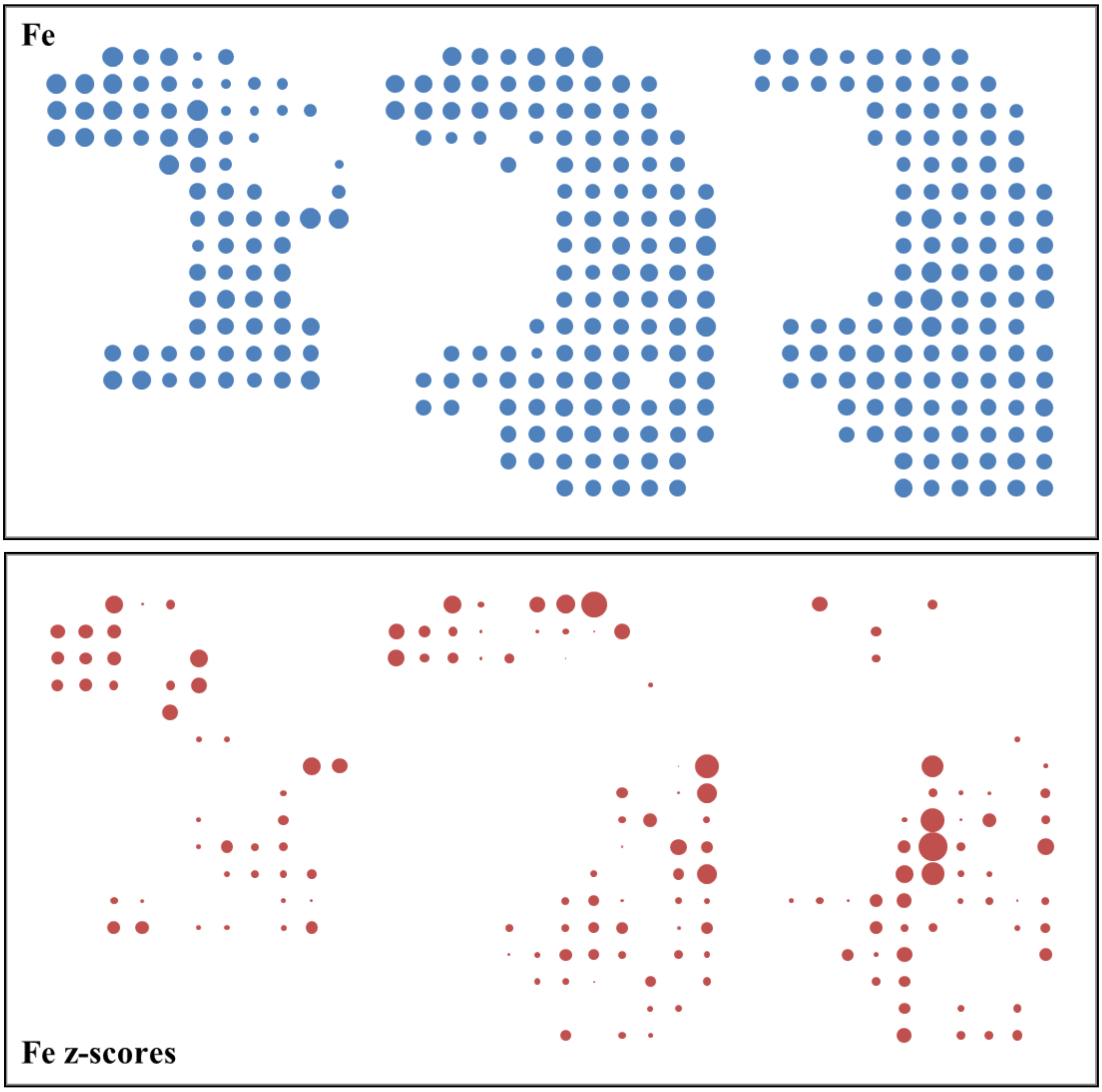

Figure 7.20 Bubble plots of (*top*) Fe concentrations (ppm) and (*bottom*) Fe z-scores in the Western House, Trench IV, Maiden Castle. *From left to right*: Floor 6851/Sample 16505; Floor 6852/Sample 16504; and Floor 6853/Sample 16503.

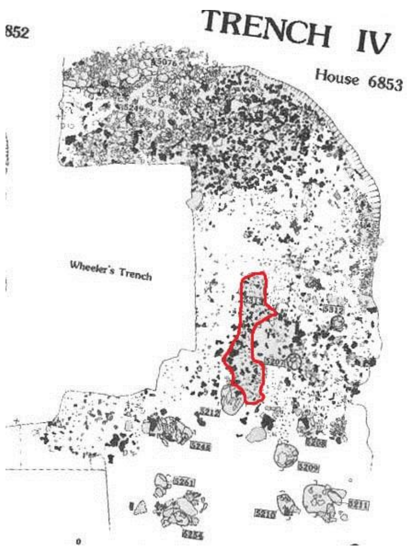

Figure 7.21 Plan of the Western House, Trench IV, Maiden Castle Phase 6G context 6853 with context 5313 outlined in red (image from Sharples 1991: 77).

MANGANESE

Levels of Mn were relatively constant over the two phases of the Western House, though at concentrations considerably greater than (*i.e.*, approximately 2450ppm *contra* 300-500ppm for the region, Table 7.2) the average for the region (BGS 2014). Yet again there are two anomalies apparent in the earliest floor level in the northern half of the house that are correlated with those of Zn, Pb, and Fe (*i.e.*, Zn r=0.75, Pb r=0.72,and Fe r=0.81). However in the later levels of the structure, Mn was evenly distributed across the house save for a few isolated anomalies. The collection of anomalies exhibited in floor layer 6852 north of the centre of the house are associated with both ferrous slag and sheetwork discovered during excavation (Figure 7.14), and could be the source of the Mn enhancement.

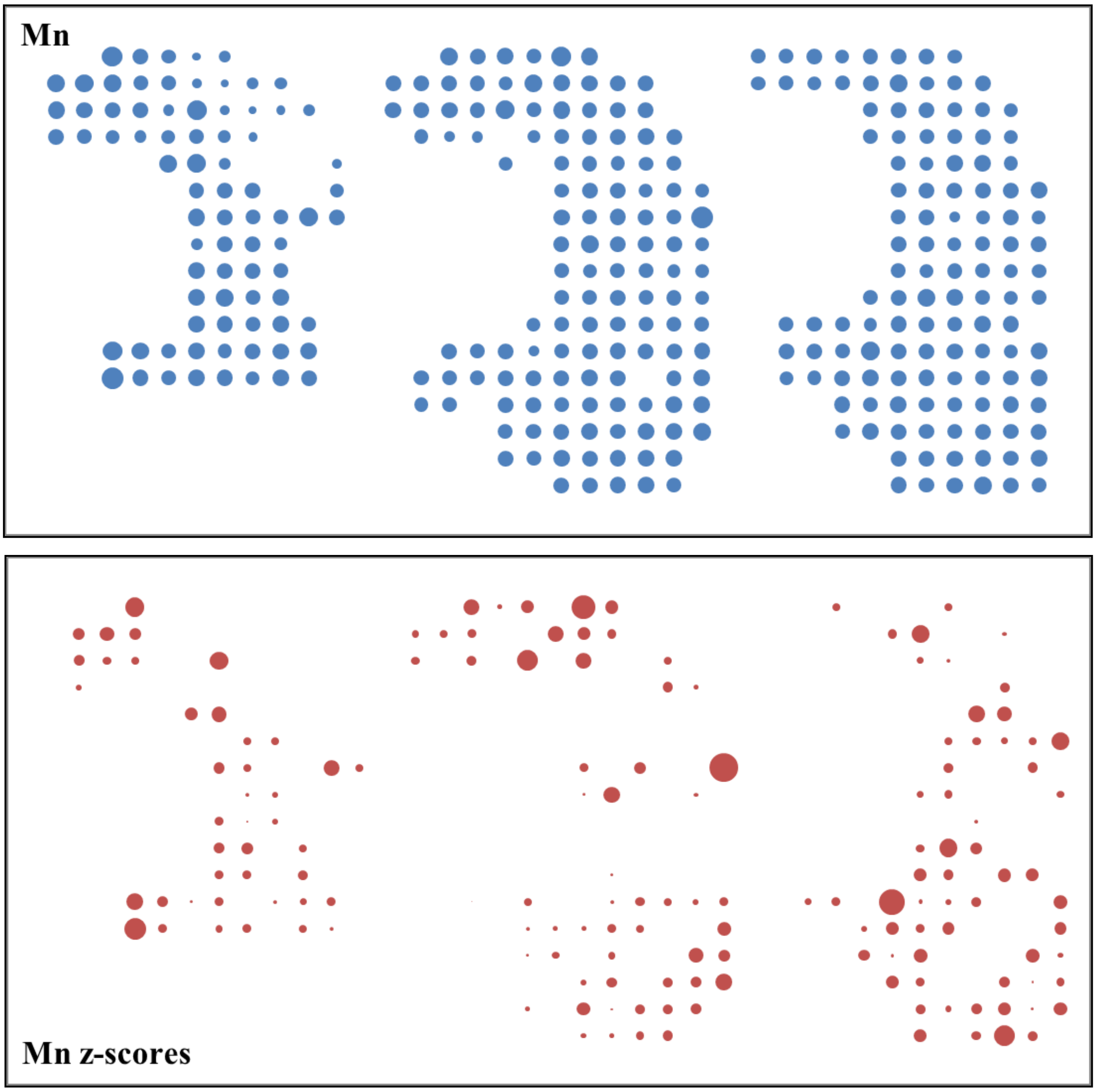

Figure 7.22 Bubble plots of (*top*) Mn concentrations (ppm) and (*bottom*) Mn z-scores in the Western House, Trench IV, Maiden Castle. *From left to right*: Floor 6851/Sample 16505; Floor 6852/Sample 16504; and Floor 6853/Sample 16503.

PHOSPHORUS

The samples from the Western House were not reanalysed for P and instead the data presented here are a replotting of the original phosphate analysis conducted as part of the Maiden Castle excavations in 1985-6 (Sharples 1991). As previously mentioned, the excavation report only made reference to two samples (*i.e.*, 16504 and 16503) retained for phosphate analysis, thus there are only P data from phase 6G to compare to other geochemical analyses. In floor level 6852, there is a structured anomaly to the east of centre that is associated with pit 5695 (Figure 7.15) within the structure. This pit contained considerable metallurgical debris, both copper-alloy and ferrous in nature (Figure 7.13 and Figure 7.14), and it is entirely plausible that other debris (*e.g.*, organic refuse or simply ash) was deposited in these pits, accounting for the increased concentration of P. For this sample there is also evidence of an anomaly near to the centre of the structure as well as two areas of relatively higher P concentrations, as evinced by z-scores, in the northwest and in the south nearest to the doorway. The anomaly at the centre of the house could potentially be associated with the oven that was referenced in Wheeler's excavation (1943) (Figure 7.10). A known source of phosphate is wood ash, however P can also be contributed through human waste, domestic refuse, and animal stalling (Holliday and Gartner 2007), making the specific origins of this central anomalies difficult to determine.

In the later floor layer of phase 6G (*i.e.*, 6853) pit 5695 is now the locus of the only P anomaly (Figure 7.23 and Figure 7.15), which has expanded in size to encompass a greater area of relatively higher P concentrations surrounding the feature. The origin of the P enhancement in the pit being wood ash rather than decomposing organic matter is further supported by the lack of corresponding magnetic susceptibility enhancements in these loci (Figure 7.24), which would be expected in the case of decomposition (Le Borgne 1955, 1960). Beyond the visible anomaly in sample 16503, the patterning of P concentrations, in particular the areas of lowest concentration, suggests a path through the interior of the house parallel to the arc of the structure (*cf.* Ullrich 2013). The entryway patterning, seemingly devoid of P, is also possibly indicative of a desire to clear the entrance of the structure of wood ash or organic debris.

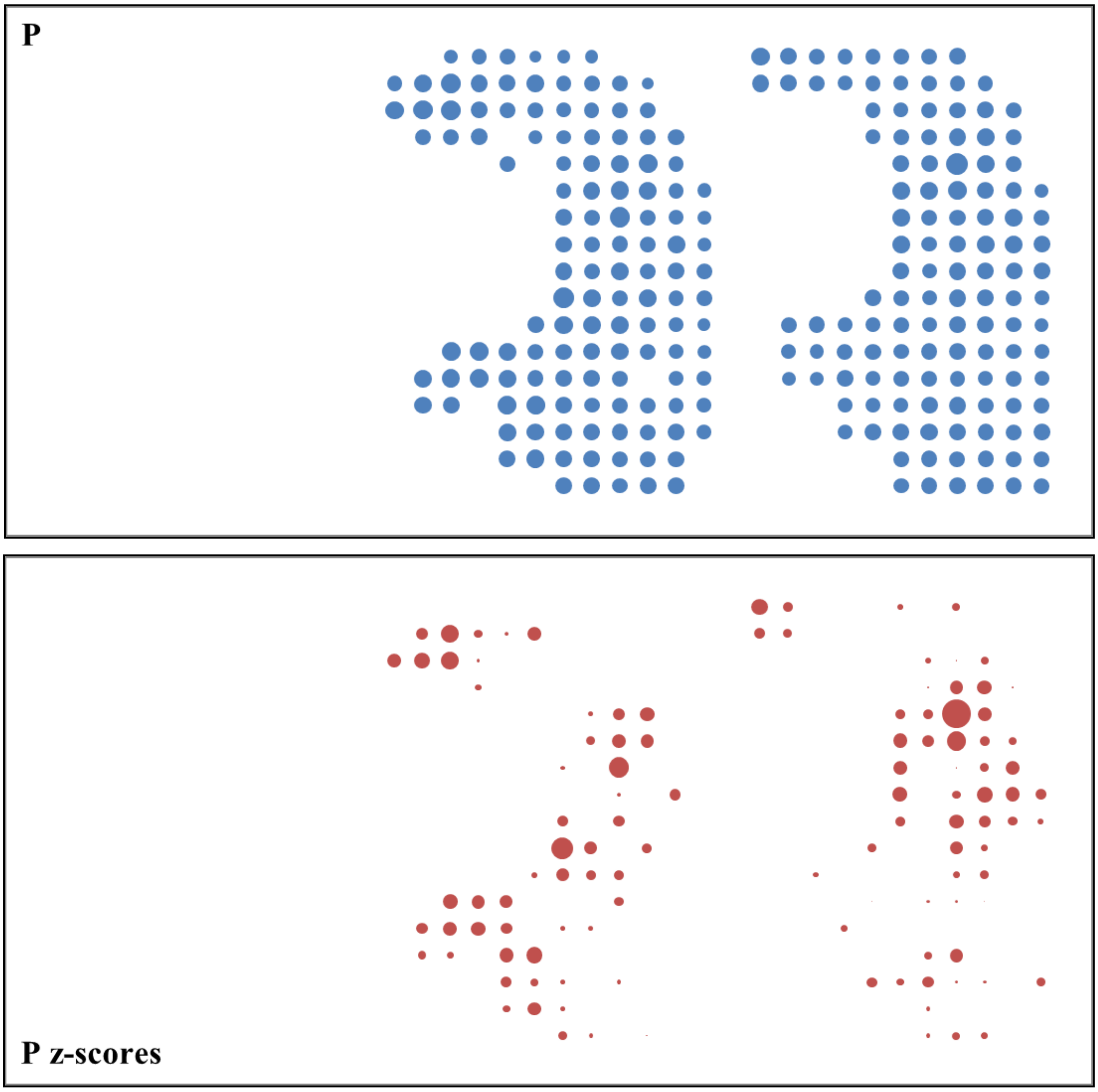

Figure 7.23 Bubble plots of (*top*) P concentrations (ppm) and (*bottom*) P z-scores in the Western House, Trench IV, Maiden Castle. *From left to right*: Floor 6851/Sample 16505; Floor 6852/Sample 16504; and Floor 6853/Sample 16503.

MAGNETIC SUSCEPTIBILITY

Magnetic susceptibility, like P, was not reappraised for this study and the data reported herein are a replotting of the results of the 1985-6 survey, representing a single phase of the Western House. In the earlier floor level (*i.e.*, 6852, sample 16504) the patterning of enhancement (Figure 7.24) does correlate with the central P anomaly (Figure 7.23), suggesting that if the P enhancement was the result of wood ash deposition from a hearth, that the temperatures of the hearth have impacted the underlying soil. The data plotted as z-scores, reveal a concentration of magnetic susceptibility enhancement ringing the centre of the house as well as in the northwest corner. There is also a suggestion of preferential enhancement in the doorway to the house.

The later floor layer (*i.e.*, 6853, sample 16503) shows a slightly different pattern of magnetic susceptibility enhancement to the earlier layer. There is a discernible anomaly east of the centre in the region of the two pits as well as an extensive anomaly in the southern portion of the house around the door (Figure 7.24). The shift from north to south in the house in terms of areas of magnetic susceptibility enhancement is pronounced, but it is difficult to posit what caused such a change.

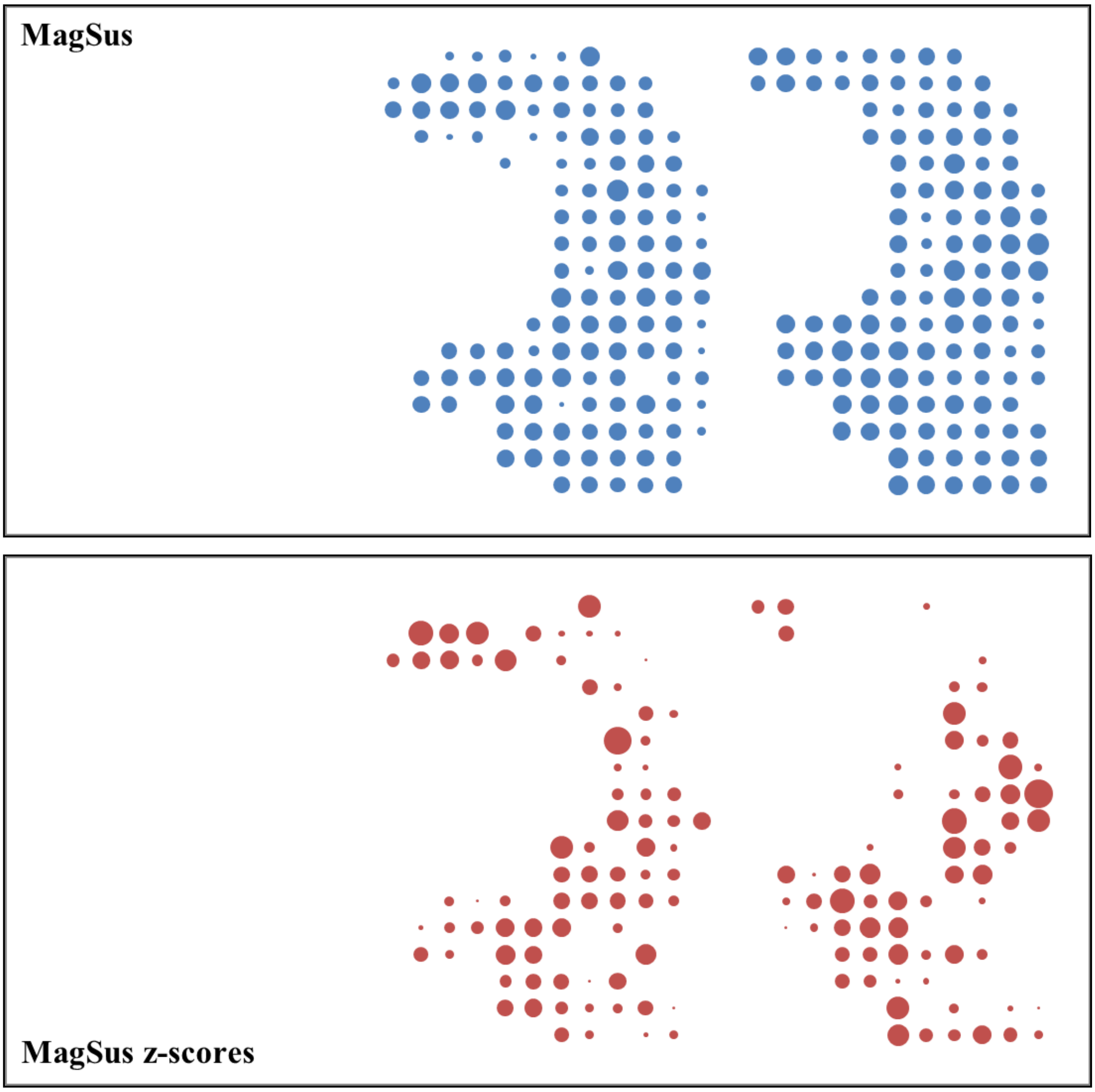

Figure 7.24 Bubble plots of (*top*) magnetic susceptibility readings and (*bottom*) magnetic susceptibility z-scores in the Western House, Trench IV, Maiden Castle. *From left to right*: Floor 6851/Sample 16505; Floor 6852/Sample 16504; and Floor 6853/Sample 16503.

SUMMARY

Artefact-based Methods – The Lake Villages

Mapping the distribution of metallurgical artefacts at Glastonbury presents a picture of a community in which metallurgical activities or actors were spatially circumscribed. The spread of crucibles, slag (both copper-alloy and ferrous), and tuyères extends across the site yet shows a notable preference for the edges of the settlement. This brief exploration has revealed a limited but nonetheless significant flourishing of activity in the Middle phase of occupation largely focused on copper-alloy metallurgy but with definite evidence of ferrous smithing as well. Whilst we cannot directly connect these artefacts in space with discrete events such as casting, perhaps we should reframe our perception of what constitutes a place of production. At Glastonbury we have evidence of at least three distinct contexts of production evincing signs of a variety of metallurgical practices. However what we know about those practices and their practitioners is frustratingly limited. Perhaps we are witnessing the remains of workshops that were the centres of production or collections of equipment that represented the staging grounds for more extensive activities. It is unclear if these artefacts represent the products of repeated smithing or casting on site, or rather the remains of a one-off event—the detritus of a travelling smith's trip to Glastonbury. Further evidence of the simultaneous or at least concurrent working of copper-alloy and ferrous metals within the same spaces for at least two areas of the site is intriguing and deserving of further inquiry. These metals seemingly united by a similar material class, required markedly different production techniques for their manipulation and evidence of them being worked within a single context raises more questions than it answers. Though for Glastonbury, those questions will remain unanswered. Without the physical contexts of production little can be done to elucidate the past practices that produced the artefacts we examine today. Through the techniques of geochemical and geophysical analysis explicated in the preceding chapter, it should become clear that the distribution of visible artefacts is merely scratching the surface of what past contexts can reveal. In light of what remains, rather than attempting to quantify or categorise the artefacts uncovered within Glastonbury to fit into neat typologies and technical parameters, we should instead consider them as a whole. Just as we can consider a biography of an object, perhaps we should envisage a biography of practice for the site as a whole in which the actions of metallurgical production extend from the procurement of resources down to the storage and/or disposal of equipment. In the end these are all purposeful acts that leave a mark in space.

Meare Lake Village presented an equally plentiful artefactual record, but without a subsequent phasing like that performed for Glastonbury, conclusions about the spatial distribution and organisation of metalworking activities our interpretations are constrained. Nonetheless there are significant differences in the character of metallurgical debris recovered from the two sites as well as the identification of metallurgical features that serve to contrast the practices which might have occurred at these two neighbouring sites in the first millennium BC. Notably, the presence of 'worked blooms' is suggestive of primary iron production, a process that is largely elusive throughout much of the Iron Age. Yet, without any furnaces noted on site, metallurgical analysis of this class of material is necessary for any further speculation as to the presence of this particular practice. Another class of artefact: anvils, are interesting for spatial studies as they are often considered to be almost architectural in character due to their limited portability, and may present one of the best opportunities to identify contexts of production. Further, Meare appears to represent a more heterogeneous community of metalworking practice with contexts of recovered copper-alloy and ferrous debris largely unsegregated. The data from Meare are incapable of demonstrating diachronic changes in the spatial arrangement of metalworking activities or even the contemporaneity of practices. However the data are able reveal that debris of metalworking activities are spatially circumscribed to particular mounds, though in a less restricted manner than witnessed at Glastonbury.

The richness of their artefactual records, in terms of the metallurgical debris, as well as the succession of preserved floors contexts, makes Glastonbury and Meare enticing sites for further study. Whilst the two Lake Villages represent a largely unique site type, fully excavated, with a plethora of artefactual evidence, the realities of their pasts remain elusive by virtue of their inadequate site records (Barrett 1987). Even in the face of superior preservation due to the waterlogged nature of the sites, without proper context, patterns of metalworking practice cannot be credibly linked in space and time. Undoubtedly the Lake Villages were never ideal sites for the study of the spatiality of metalworking activities. More importantly, however, the analysis of their published remains serves well to illustrate what data are necessary to fully interrogate past craft practices.

Integrated Methods – Maiden Castle

The artefactual evidence from Trench IV, Maiden Castle presents a picture of a shifting focus from ferrous to copper-alloy metallurgy as well as a change in the distribution of such activities from phase 6F to 6G. Evidence of ferrous metallurgy dominates the early phases and is mainly spatially restricted to the Central House and the eastern most area of the trench. By the latter phase, the focus of metallurgical debris deposition has shifted to the Western House and the area immediately outside of the structure. The identifiable shift in emphasis on to the Western House for deposition of metallurgical debris, as well as the preservation of soil samples from its floor contexts, presented an ideal opportunity for the integration of artefactual and geochemical/geophysical methods to understand the spatiality of practice.

Analysis of the floor layers from the Western House has demonstrated both variation and continuity across the contexts in terms of geochemistry. Copper exhibited structured variation and therefore holds some interpretative value in relation to the artefactual evidence. The results from copper seem to show the clearest patterning and the implications are that copper metallurgy was, in some way, associated with these anomalies. Of course, such inferences are based on the artefact associations that have been recovered from these contexts. In Phase 6G pit 5622 which is associated with areas of increased copper concentration, has produced an abundance of evidence of metallurgical activity ranging from copper slag, copper-alloy sheet fragments, ferrous fuel ash slag, and iron sheet fragments. Confidence in these distributions of concentrations is given by the associated artefact locations. As such it is the artefactual record which gives confidence to the geochemical data in that it signifies the presence of specific practices, or the products of those practices, which would have been likely to impact on geochemical variation.

Though there was also considerable evidence of ferrous metallurgical debris within the structure across both phases, the Fe concentrations were generally not correlated with the contexts of these finds. Of the other elements measured, Pb, Zn, and Mn did demonstrate some shifts in pattern and concentration over the two phases. However, these elements were of limited interpretative value, generally not associated with metallurgical debris, or each other. Whilst the results of this reappraisal are not as clear as some other geochemical analyses it is apparent there is was some patterning observed within the house and ultimately some potential for the study of this material.

The comparison of magnetic susceptibility and pXRF results alongside the distribution of metalworking debris provides an opportunity to expound further upon the question of just what constitutes metallurgical practice. When these data are layered it is easy to dismiss their lack of positive correlations as the result of unknown post-depositional processes. Rather we should consider that these distinct categories of evidence can present equally valid pictures of productive activities. The palimpsest of geochemical, geophysical, and artefactual remains is in fact manifest past practice. The apparent negative correlations between these data can reveal how differing activities impacted the archaeological record in varying manners. In summary the reanalysis of Maiden Castle sediment samples has provided some insight in to temporal variation of elemental concentrations within the Western House and together with the artefactual data can give value to the patterns in order to recognise signatures of practice(s) which would have been likely to impact on geochemical variation.

Chapter 8. Discussion

> *'Space is not the setting (real or logical) in which things are arranged, but the means whereby the position of things becomes possible' (Merleau-Ponty 2002: 284).*

Discussions of space, and its use, abound within archaeological texts, yet as a concept, it is often loosely defined and in turn remains poorly understood. An analysis of the work of Heidegger, Giddens, Ingold, and others (see above) has explicated that space is not a reservoir for action nor an empty surface waiting to be occupied (Heidegger 1962, Giddens 1979, 1984, Ingold 1993, 2000), rather it should be thought of as something actively created through behaviours and recreated through inhabited acts. Spatial analyses within archaeology have rarely been grounded in this conception of space, rather viewing it in the Cartesian sense as *a priori*, waiting to be filled by actions and individuals. Archaeology has been most adept at studying the distribution of monuments and artefact types across broad regions in hopes of delimiting the bounds of cultural groups or architectural phenomena (Hodder 1977, Hodder and Orton 1976). Largely the study of space in archaeology has focused on mapping archaeological evidence at a number of scales, rather than thinking space through, or experiencing it, in terms of how it was inhabited. There have been moves towards a more human-centred approach to space in the wide-ranging literature that covers access analysis and phenomenology (*e.g.*, Foster 1989a, Fisher 2009, Tilley 1994). Whilst the individual is ostensibly at the centre of access analyses, these are in essence architectural analyses that have adopted an embodied approach to understand how architecture facilitates and constrains behaviour. Often these analyses serve only to map *potential* action rather than actual evidence of past movements and interactions in space. In these cases, architecture plays a powerful role as it acts as a crutch to infer routine behaviours in terms of how a space was accessed. Such analyses, along with many archaeological studies, have focused towards space bounded by architecture, often monumental, and have paid scant attention to routinised behaviours that unfold in *localised* spaces not bound by permanent architecture. Phenomenological approaches within archaeology have expanded the repertoire of spatially centred research to focus on the experience of the individual within space (Gillings 2012, Tilley 1994). These situated explorations of space move towards suggesting how individuals might have experienced past landscapes, yet in many respects these analyses stray away from the distinct, supposedly poorly defined, spaces in which everyday life often goes on. These phenomenological accounts have much in common with Ingold's wayfaring (Ingold 2011) rather than any particular ability to characterise places and spaces. The focus is on movement *through* rather than the routinised practices *within* a space.

These archaeological approaches to space have addressed opposing scales of analysis, tightly demarcated monumental architectural space at one end and the extended environment or ranging landscape with natural and anthropogenic features at the other. The spaces within settlements and peripatetic encampments are another type of space and likely to have witnessed the routine comings, doings, and goings on of daily life (*i.e.*, the routines of day to day practice). Craft production is one such day to day practice which can be considered routinised through the habits associated with particular traditions of making. These routine practices often unfold without significant or monumental architecture and as such, the spaces might be thought of, superficially at least, as being weakly structured. Unlike the effects of imposing architecture on practice, craft practice often delineates its own loci of action through routine behaviours, habitual practices and in turn, the structured deposition of material residues.

In the case of metallurgical activity, there are inherent dangers of working with fire at temperatures commonly exceeding 1000 °C, which generally serve to isolate these activities within particular areas or 'quarters'. Moreover, the fixity of the productive architecture (*e.g.*, furnaces and hearths) of metallurgical practice necessitates a situatedness and inhabitation of place, manifested in a 'tethering' of the body to the furnace over extended periods of time. The operation of bellows is another demanding process that requires immediate proximity to the furnace or hearth. The need to carefully control the timing and rhythm of metallurgical activities (*e.g.*, copper alloy casting, iron smelting, iron smithing) directly impacts the manner in which loci of production are organised. Processes such as the smithing of iron, which necessitate both a swiftness of practice as well as a tightness of space, reveal how practice becomes articulated in space through the careful arrangement of hearth, anvil, and tool storage areas, *etc*.

Despite this propensity for craft to be firmly located within space, recognition of this dimension in craft studies has been enduringly absent. Attempts at an archaeology of agency in craft have been incomplete as analyses have always emphasised the material dimensions of technology at the expense of the spatial (Dobres 1995, 2000). Approaches that have attended to the material dimensions have sought to identify choice in material selection, transformative process, and choice of fabrication technique (Lemonnier 1993, Van der Leeuw 1993), ignoring the spatial. Despite appeals for a more holistic study of technology (Dobres 2000), space has rarely been recognised as a *technological choice* itself. Space can be thought of being chosen in two main ways: primarily in the location of practice (*i.e.*, where in the landscape craft activities are situated), but also in terms of how space is used as the routines of production serve to define *signatures of practice*.

PRACTICE MAKES PLACE

In order to study the impact of routinised behaviours in space, we must be able to appreciate (both theoretically and archaeologically) the places that these actions made recognisable—those arenas of practice that constitute place. Place has often been equated with spaces delimited by architecture and indeed architecture is a very powerful yet unsubtle means of creating place. However place is much more than permanently bounded space. As considered previously, place has many monikers: *Umwelts*, fields of discourse, taskscapes, *etc*. (Barrett 1988, Ingold 2000). All of these conceptions of place share the common premise that place, rather than representing a container for action to fill, is the arena that comes into existence as practices are enacted. While it is those practices that serve to produce and reproduce places as routinised behaviours are carried out, the structured deposition of residues serves as a tangible material condition that substantiates the *sense* of place. Craft then may not involve monumental architecture, but nonetheless effectively creates place through the routine deposition of residues which in turn define, to an extent, the material conditions for future practice. For metallurgy, this sense of place is borne out through the hearth and its relation to slagheaps, ash scatters, and raw material ‘dumps’. In comparison to monuments, these residues are ephemeral, yet these products of daily routines not only testify to those arenas of practices as constituting place, but they also act as historical indicators to the specific syntax of production routines. They are polyphonic in that they not only signify material transformation but together they highlight the spatial articulation of a transformative process.

Place then becomes both meaningful and defined, as significance accretes to a locale through the vehicle of actions and the residues that such actions create. These actions make manifest these places through the routine transformation of spaces and materials, which in a recursive manner further serve to sustain the practices these places facilitate (Tuan 1977).

Recognising the significance of these types of spaces, ephemeral as they are, has important implications for archaeological practice. In acknowledging craft places as a meaningfully constituted space which is potentially recoverable archaeologically, we commit ourselves to: a) necessarily expanding our theory of craft to accommodate space and b) better developing empirical methods to recover such evidence.

AGENCY AND THE INDIVIDUAL

Craft studies have the facility to identify technical choice through artefactual analysis, often revealing individual actions in the pinch of a pot rim (Van der Leeuw 1993), the location of a sprue in a casting, or evidence of quenching in the microstructure of a knife. While study of the techniques of artefact production can reveal individual choices, these are the actions of the sole crafter decontextualised from the arena in which they were produced. Unlike technical choices, the material residues of practice, that collectively give rise to *signatures of practice*, do not reveal individual choice in the same manner. Instead, *signatures of practice* are the amalgamation of individuals' routinised actions, they are a cumulative phenomenon. Soil residues and distributions of slag or pottery are the result of routine cumulative practices.

In a similar vein, in coming to understand architecture, archaeologists have re-inhabited space and explored the individual and his or her actions within particular locales (Cutting 2003, Fisher 2009, Parker Pearson and Richards 1994a). However to incorporate space into craft studies, we can conveniently extend our analysis beyond the individual. It becomes clear that though actions are constrained by and considered through the medium of the body, the residues of those actions do not represent a singular individual act. The excavated residues of past actions are the product of individuals' agency but we must be careful not to conflate residues of agency with evidence of the specific agents themselves. What are captured in the soil are *signatures of practice*, the collective traces of quotidian actions performed in a routine and spatially circumscribed manner.

THE EXPERIENCE OF EXPERIMENTATION

Recovering the material residues of past actions to construct signatures of practice is a multi-faceted process. Microdebitage studies, geophysics and geochemistry are complementary techniques and some, especially geochemistry, cannot be employed as standalone means of characterising past activities writ in the soil. While geochemistry can usefully identify variation in prospection studies, it struggles to characterise the specific nature of practices when used independently of other evidence. To date, geochemistry has in many ways been utilised in a theoretically uncritical manner (Cornell and Fahlander 2002). Studies have at times utilised geochemical data to prospect for sites and activities by comparing elemental concentrations against expected mean. The recognition of anomalous geochemistry can be indicative of past occupation or practice; however, it is unwise to treat these data as absolutes. Geophysical data, which is routinely utilised to prospect for sites, or features within them, is not used in a similarly uncritical fashion (Gaffney and Gater 2003, Clark 1996). Rather, the data produced via geophysical methods is considered relative and merely indicative of patterns, or signatures, of underlying archaeology. Geochemical data must be treated in the same manner. Geochemical methods, like geophysical ones, are empirical, but they are essentially qualitative rather than quantitative. The data produced via such methods can only serve to illustrate patterns within the soil, not serve as a direct cipher for past activities.

Experimental analysis has demonstrated how the actions of multiple individuals in a metalworking context are coalesced into a single signature of practice which is recoverable through geochemistry, geophysics, and artefactual debris. In particular, the application of time-geography to Experiment IV highlighted how observable routines impacted upon open soil contexts, while it also demonstrated the inability to identify specific individuals through routine practice. The movements, and rhythms of work witnessed in the time-geography analysis revealed how the practice of a craft—that is the effective bringing together of materials and technique to define a particular type of technical performance—and features of production afforded certain routinised behaviours and how these actions then gave rise to a particular set of deposits. Intriguingly, an analysis of the time-space paths of the practitioners and the places delineated by them was ill-equipped to discriminate individual experimenters. As was witnessed in the experiment, the residues of practice of metallurgical production do not emphasise the individual practitioners, but rather by means of semiosis those practitioners become unidentifiable, and are only distinguishable by their actions, preserved in the soil only as the residues of their practice (Owoc 2005). Time-geography ultimately recorded aspects of *agency* rather than the time-space paths of the specific agents. The agents, though not absent, were essentially subsumed by their practices. Owoc has explored this idea through the paired concepts of practice and *praxis*. Her conception of *praxis* is similar to that of signatures of practice, acknowledging that

> *'[t]hough a product of them,* praxis *is not reducible to individuals and moreover, exists within a network of relationships and exchange. Practice is therefore always to some extent collective—a "shared practice" involving persons oriented towards one another at immediate or more distant time–space levels' (Owoc 2005: 262).*

Experimental metallurgical production has revealed the ease with which actors produce and reproduce *Umwelts* (*i.e.*, their arenas of practice). However the time-geography experiment has gone further to illustrate how aspects of agency rather than actors produce these *Umwelts*. It is not the actions of a specific agent that create and perpetuate the *Umwelts* observed in the experimental copper smelting programme, rather the collection of practices produces, moreover gives birth to, its own arena.

The results of the campaign of experimental metallurgical work have demonstrated the ability of analytical methods, undertaken at a range of scales and utilised in concert with a theoretical grounding in agency, to reveal elements of practice that have to date been overlooked. In regard to experimental studies, it is apparent that even very ephemeral activities undertaken on open soil contexts can leave a measurable signature. The chemical and physical transformation of soil contexts offers then the potential of exploring craft practice from a perspective beyond the material itself. Metallurgical practices are often easily identifiable in the archaeological record and a number of environmental studies have demonstrated their propensity to impact on their immediate and regional environs through deposition of heavy metals (López Varela and Dore 2010, Oonk *et al.* 2009a). Such studies have been successful at demonstrating the earliest environmental impact of metal exploitation along with fluctuations in practice through time (Mighall and Chambers 1993). However, these studies have rarely commented directly on the scale of production. The experimental programme reported here has demonstrated the impact of very low-scale activities. The results indicate the potential for such approaches to demonstrate the utility of high-resolution geochemical and geophysical analysis of metallurgical production contexts, paired with traditional architectural and macroscopic debris analyses, for elucidating past practice in archaeological contexts.

THE APPLICATION OF EXPERIENCE

Through highlighting how routine craft practices themselves come to define places, we can in turn consider how we might better explore the idea of structured deposition in contexts of production. Structured deposition has been a term used largely in prehistoric studies that have aimed to invest meaning in archaeological deposits that have been considered the result of casual disposal or undefined taphonomic processes (Hill 1995, Lawson 1994, Chadwick 2012, Bradley 1998, Pollard 1995). Craft production is intimately associated with the idea of waste products, ash, slag and hammerscale; too often even monumental deposits, *i.e.*, slag heaps, are considered little more than discard. When such deposits are rethought as structured deposits that come about as the residues of routinised behaviour, *i.e.*, behaviour which is culturally informed, they take on an archaeological value, not just in their ability to be characterised, but as potentially powerful and sophisticated means of comparative analysis.

At Glastonbury (Bulleid and Gray 1911, Bulleid and Gray 1917, Coles and Minnitt 1995) and Meare Lake Villages (Bulleid and Gray 1948, Gray 1966, Gray and Bulleid 1953) there is certain evidence of structured deposition in the distribution of metallurgical debris concentrated upon specific mounds. Between Glastonbury and Meare Lake Village, Meare is evidently the more metallurgically diverse site, exhibiting residues of cast and beaten copper-alloys as well as debris from iron smithing and potentially smelting. Glastonbury presented a much more restricted set of practices with only evidence of cast copper-alloys and iron smithing slag. The evidence for metallurgical practice at both Lake Villages was found across the settlement, though spatially confined to particular mounds, suggestive of a localisation but perhaps not a segregation of practice.

Glastonbury, having benefited further from a phasing of the site, has both spatial and temporal resolution and it is possible to illustrate changing settlement organisation through shifting contexts of practice. The metallurgical debris from both Glastonbury and Meare, although significant in quantity, has seldom been held up as a conclusive evidence of contexts of metallurgical production. This conclusion is largely the product of our inability to consider discard as an active part of production. We acknowledge that features such as slagheaps are evidence of metallurgical production, but we often fail to make the connection between the act of the production (*i.e.*, the smelt) and the discard of waste. Slagheaps would not exist without the routinised practice that sees their creation. While their presence shows the spatial significance of those specific practices, they are neither the product of singular events nor the result of random wide ranging discard, but instead a palimpsest of many actions and activities over time that have adhered to a specific spatially circumscribed practice. In a similar vein, the debris from Glastonbury and Meare in its concentrated distributions is representative of routine practices of deposition. Crucibles had limited use-life and would, invariably, be discarded. The presence of vitrified crucibles on a restricted set of mounds on these sites is one aspect of the material record that constitutes an, admittedly crude, signature of practice. As such, it is likely that it would have benefited from being investigated further using geochemical and geophysical techniques.

The case of Maiden Castle perhaps represents the ideal in terms of an archaeological investigation to which the techniques for analysing signatures of practice can be applied. Unlike the Lake Villages, Maiden Castle was exceptionally well-phased, particularly in the later excavations of Sharples (Wheeler 1943, Sharples 1991), though excavated at a considerably less extensive scale. Artefacts were carefully recorded and retained along with a systematic programme of soil sampling for magnetic susceptibility and phosphate analysis. The single context recording of the Maiden Castle excavation provided the necessary spatial and temporal resolution to facilitate detailed analysis of production space. Trench IV (Sharples 1991) and Trench D (Wheeler 1943) present convincing evidence of copper-alloy and ferrous metallurgical practice throughout the excavated areas. There is further evidence of ferrous metallurgy in a later phase at the eastern entrance. This practice is located in a conspicuous position at the gateway to the hillfort, in contrast to the activities in the western corner (*i.e.*, the location of Trenches IV and D) that are more isolated—positioned in the lee of the rampart. The scale of production demonstrated between the two areas of Maiden Castle is also markedly different. The metalworking by the entrance produced so much ash as to appear to have been the result of a burning event, making one wonder at the spectacle that might have presented itself when these activities took place. In the western corner of the site there is cast and beaten copper-alloy debris alongside iron smithing residues—a suite of evidence that is very similar to Glastonbury. Whilst the extensive spread of metallurgical debris within this area makes it impossible to deny the presence of metallurgical practice, the scale of practice is so limited as to make any firm conclusions about the nature or organisation of the practice nigh impossible. In combination with geochemical and geophysical data for the site, however, we were able to begin to construct particular signatures of practice. Rather than simple correlations between artefactual, chemical, and physical evidence, complex patterns of interaction between distributions of material, soil chemistry, and soil magnetism were observed, indicating that these strands of evidence were independent but complementary. In the case of Maiden Castle these geochemical and geophysical data however, were produced from samples not taken to assess the nature of metalworking. Rather the samples were collected in order to measure phosphate in relation to domestic structures. Thus our data based upon the reappraisal of these samples cannot see the spaces between the structures, the extramural areas where metallurgical likely took place. Providing further confirmation that analytical techniques are only capable of answering the questions posed of them and that we must be well informed in our decisions to apply them (Latour and Woolgar 1986).

In a manner similar to material based technology studies where chemical, microstructural, and typological data rarely, if ever, correlate completely, it is unreasonable to expect simple correlations between different datasets. The challenge then, for those seeking to better understand how space is constituted in production contexts, is to begin to understand and recognise the complex relations that exist between these particular strands of evidence. For instance, while it may remain possible to define *signatures of practice* in a variety of contexts, it is more difficult to determine whether these relate to discard activities, transformative processes, or both. Taken together, both discard and transformative processes contribute to signatures of practice, yet being able to characterise these specifically in terms of practice and location in space will add significantly to our ability to use such analytical frames of reference in a more meaningful way. From this perspective, it is apparent that when our theory of technology is expanded to include space as an element of choice, the locus of technology studies expands from the laboratory to the field. This shift is important, as through extending what is otherwise often deemed a ‘post-ex’ activity into the field in pursuit of production contexts, the study of technology develops beyond the laboratory—and the scientism inherent therein (Latour and Woolgar 1986, Barrett 1990). While the debate concerning archaeology as a science is well rehearsed, bringing archaeological specialists normally confined to the laboratory into the field to work along field practitioners, can only enhance the interdisciplinary nature of archaeology while simultaneously enhancing the opportunity for such studies to be used to inform excavations strategy (Andrews *et al.* 2000, Andrews and Doonan 2003).

SCALING UP

Just as residues of practice are accumulations of individual actions, signatures of practice can be used analytically to identify communities of practice across space and through time. What is meant by *community of practice* is an analytical entity which unites various contexts of production, which share common signatures of practice alongside comparable material culture. Defined in these terms, communities of practice exist at the regional and micro-regional level and lend themselves to comparative analysis—representing a rich multivariate constellation of archaeological data. It is in this way that communities of practice become powerful. First, they too, like signatures of practice, amalgamate practice by coalescing the residues of individuals and their actions. Second, as an analytical unit, like formal typologies, communities of practice extend across space and through time. But these communities are sophisticated analytical entities which are made up of nestled practices and multivariate parameters at a scale unseen in formal typologies. This amalgamation of practices moves so far beyond the individual as to witness the social dimension of technologies. Further, *communities of practice* can be thought of as having a *lineage* of practice which allows the examination of change through time, in a manner which can better reveal the dynamic aspects that are so often difficult to accommodate within diachronic studies that utilise simplistic analytical units.

There is potential for communities of practice to be thought of as middle range analyses; in that they transcend the individual yet remain meaningful in terms of culturally informed practice, while they are the result of collective social practice. The amalgamated and dispersed nature of communities of practice means that they are more likely to exhibit the strategies of participation that allowed communities to engage in more abstract cultural systems such as economy (Hanks and Doonan 2009, 2012). It is their propensity to exhibit irreducible emergent properties that gives them the potential to be simultaneously scrutinised in terms of agency and structure (Giddens 1984).

RECONTEXTUALISING THE PAST

The nested concepts of residues, signatures, and communities of practice have the potential to address key issues for the Iron Age including territories, expanding horizons, and the idea of community itself. Studies have widely recognised the period's attention to how space was used and the acknowledgement that space becomes a powerful means for symbolic expression by Iron Age communities (*e.g.*, Oswald 1991, 1997, Hingley 1990a, Chadwick Hawkes 1994, Fitzpatrick 1994, 1995, Parker Pearson 1996, Pope 2007). If the investment in defining space that is witnessed in the Iron Age is the result of an increasing consciousness of the power of place, then it is the formalisation of practice through which this is realised (Lawrence and Low 1990). If as Bourdieu and Giddens hold that the recursive nature of behaviour feeds back to create these places, we must be able to identify or distinguish the constituent practices and actions that are preserved therein (Bourdieu 1977, Giddens 1979, 1984). We should then be more aware of and able to recognise these practices archaeologically and to develop convincing approaches to their analysis at varying scales. Here we have argued that the routine application of the geochemical and geophysical techniques is one way that we might do this.

In recognising the changing values towards space in the Iron Age (Barrett 2006), researchers have begun to innovate in field practice (Parker Pearson *et al.* 2004); yet there remains a sense that such techniques are expensive and time consuming, with the result that there remains little data for excavated contexts. In light of the present scenario in the UK, where recently most major Iron Age site excavations have been undertaken by commercial units as part of the development process (Cooper and Edmonds 2007, Knight 2012, 2009), there may be resistance to augmenting such supposedly time inefficient processes. However, this need not necessarily be the case with careful targeting and sensible deployment of resources. The routine application of the methods discussed herein can serve to elucidate how space was occupied and formalised in the Iron Age in a way that moves beyond architecture and monuments, and into the realm of the quotidian and mundane, where practice and ultimately social structures are reproduced.

Chapter 9. Conclusions

> *'Human history is created by intentional activities but is not an intended project' (Giddens 1984: 27).*

An enduring theme of this thesis has been to develop and advocate an expanded view of craft practice that accommodates more than material and technique. It has been argued that space is an essential aspect of craft yet often unrecognised, and hence underdeveloped, within craft studies. The idea of space as a *technological choice* might appear odd, but the routines of practice are as much spatially, as they are materially, derived. Craft studies have long explored composition, provenance, and process, and in doing so, have developed specific tools and methods for building knowledge upon such data. While provenance studies routinely contribute to discussion of economy (Gale 2001, Henderson 2013) and composition is understood as cultural choice (Hosler 1996, Sillar and Tite 2000), there are no existing routine frameworks that permit the discussion of space and craft to contribute to wider archaeological syntheses. It is in this light that this study has sought to understand how spatial patterns uncovered by empirical analysis can be afforded a kind of epistemological currency that will admit them in to wider archaeological syntheses.

In order to facilitate this research, a series of analytical categories were developed that built upon an understanding of how space might be employed in archaeological syntheses. Understanding spatial patterns as signatures of practice opened them up to be comprehended, on the one hand, as a kind of space-centred craft typology, whilst on the other, individual signatures could be thought of, in part, as the result of people coming to terms with their own world (Heidegger 1962, Ingold 2000). As comparative devices *signatures of practice* have considerable potential, but not simply as a novel way of describing difference and sameness. Through recognising similarities in *signatures* across a number of contexts that witness comparable craft practice, we can start to construct assemblages of signatures or what have been called here *communities of practice*. As argued above, a community of practice is an extended phenomenon that ties together similar lifeways across space, and potentially through time. In doing so, we can potentially not only see the geographic extent of particular ways of coming to know the world, but we can also explore the social depth of such phenomena. More importantly, we can see the existence of a *community of practice* as testifying to the viability of a set of lifeways, as it is through these that practices become social and shared and confer the ability to participate in wider social arenas (Giddens 1984, Dobres 2000, Lefebvre 1991, Barrett 1988, Gosden 1994). This conclusion is significant, as it reveals *communities of practice* as not only a useful analytical construct, but also a means by which to explore craft beyond individual practice, as a historically situated process that socialises materials, understandings, and memory

Whilst signatures of practice might be constructed from a range of empirical data, and at varying scales, the spatial dimensions of these signatures can remain difficult to explore. Primary architectural remains and archaeological features can be explored through the medium of the body during the process of excavation or recording (Barrett 1994, 2000); however, the dynamic and engaged nature of craft brings to bear a largely differing set of bodily conventions in interacting with features. For instance, to understand how one might interact with a shaft furnace is completely different when it is revealed as a burnt halo on an archaeological site compared to when it is reconstructed to full height, alight, and needing to have bellows pumped vigorously. Realising this distinction in the dynamic role played by metallurgical features and the ways in which they actively structure practice, we are brought to an important conclusion. While we can detect spatial patterns and represent them in a variety of ways, craft remains inscrutable, unless it is somehow brought to life through practice. Experimental archaeology therefore becomes a valuable means by which to explore how dynamically active features (*i.e.*, metallurgical architecture) facilitate and constrain a variety of actions. Such reconstructions will always be fragmentary and incomplete, yet the material and transformative nature of craft offers significant advantages to reconstruction compared to other more static forms of architecture (*e.g.*, roundhouses). Craft, especially pyrotechnical ones, transform materials under definable conditions. Thermodynamics, chemistry, and material properties all serve to define a restricted range of conditions under which a technology might be considered viable. These constraints are what serve to limit the variability of a technological process but also the actions of the craftworker engaged in that process. For instance, when smelting iron, it is likely that at least two individuals are required, one responsible for pumping bellows to maintain temperature and the other the preparation and charging of ore and charcoal into the furnace. The two roles of these individuals necessitate physical engagement with the architecture of production as well as each other to allow a process to proceed and in doing so, the strong ties between material, features, conditions, and the body are confirmed. From this perspective we can begin to see experimental archaeology as providing much more than a means to test hypotheses relating to material processes. Instead, and like archaeology itself, it becomes an enquiry into the history of how people from times past may have understood their world and the consequence of their actions (Doonan 2013).

In situating the study broadly within the issues of the first millennium BC this thesis set out to explore these expansive ideas of craft within the context of the Iron Age. This period was chosen for the scholarly emphasis on space in this period (Parker Pearson 1996, Parker Pearson and Richards 1994, Fitzpatrick 1994, Bowden and McOmish 1987, 1989, Sharples 2010). Despite almost three decades of scholarship that has sought to socialise technology (Lemonnier and Pfaffenberger 1989, Pfaffenberger 1988, 1992, 2001, 1999, Bijker *et al.* 1987, Dobres 1999, Edmonds 1990, Ingold 1990, Ingold 1988, 1997, Latour 1991, Lechtman and Steinberg 1979) it is surprising that so few studies have actually dealt explicitly with craft and space in the Iron Age. This absence would force us to conclude that there remains a very real issue in how technology studies are accommodated within Iron Age studies specifically and in archaeology generally.

The investigation of a number of contexts of production through varied methods suggested that space was a useful concept allied to the study of craft, but to maximise the effectiveness of such methods it would be desirable to coordinate purposeful sampling strategies alongside excavation itself. From this perspective we can begin to rethink the study of craft as not something undertaken as post-ex or in the laboratory, but as something that is part of routine archaeological practice that is, like so much archaeology, initiated in the field.

In establishing so called *signatures of practice* we have drawn attention to a number of analytical means, some novel, and others well established within archaeological practice. The value of these techniques has been shown to be variable, yet an overarching conclusion is that applied in isolation, they are of limited use; however, it is the broader application of these methods that needs to be considered here. The programme of experimental reconstruction demonstrated how even very ephemeral activities can have a detectable impact on open soil contexts. Whilst many relations between chemistry, geophysics, and practice might be straightforward, for instance copper metallurgy leading to elevated copper levels in soil or iron smithing giving rise to magnetic enhancement, we should not overlook more subtle associations. The experimental programme demonstrated that ash from hearths and furnaces made a significant contribution to many arenas of practice, yet its generic nature may cause it to be overlooked. While this might be understandable, such signatures can retain a meaningful significance when detected alongside other artefacts. Serving to emphasise the point that such explorations of space are not reliant on standalone analytical methods but rather need a combination of evidence from a number of techniques produced at a variety of scales ranging from features and artefacts down to the atomic.

In Britain the investigation of archaeological contexts is invariably driven by a research framework (*e.g.*, Haselgrove *et al.* 2001, Hancocks 2002, Kidd 2009, Roskams and Whyman 2005, Webster 2008, White 2002, Wigley 2002). Such frameworks have become vital documents when assembling a project design, and serve to guide many aspects of archaeological enquiry. The nature of archaeology has always been towards generating material evidence to support the writing of histories, and in this respect, archaeologists have tended to target features, architecture, and finds. Whilst this practice is understandable, it has meant that the spaces *in between* these more enduring aspects of the archaeological record have often been overlooked, despite these places commonly bearing evidence of everyday activities. There would seem to be an increasingly strong case for these forgotten contexts to be investigated in more detail. Clearly, to embark on the detailed study of *emptiness* would be ludicrous, but the targeted examination of craft features in more detail, than perhaps what they might routinely receive, seems sensible. The increasingly availability of portable geochemical and geophysical equipment means that many of the traditional barriers of cost and time are now being removed. Likewise, the sophisticated software that features on many new generation HHpXRF analysers (Frahm and Doonan 2013), means that a detailed knowledge of chemistry is no longer required at the point of sampling; allowing for such equipment to be readily employed in the field by easily trained archaeologists. To suggest such deployment as a matter of routine might be premature, but initiatives such as Framework Archaeology (Andrews *et al.* 2000), with its emphasis on space and the relation between features, would suggest that such techniques and methods could make a very real impact.

FUTURE RESEARCH

The methods proposed herein are by no means infallible and could benefit greatly from continued experimentation. First, future research must focus on longitudinal studies of the behaviour of major elements in a variety of soils and sediments. The geochemical portion of this research was predicated upon the known propensity of heavy metals to persist in soils and sediments over lengthy periods of time (*e.g.*, Aston *et al.* 1998, Carey 2007, Carr *et al.* 2008, Cook *et al.* 2005, Cook *et al.* 2010, Parnell *et al.* 2002, von Steiger *et al.* 1996). However it was noted during the experimental portion of this thesis research that other lighter elements, in particular some of which are major elements, were sensitive proxies for the practices that took place over the experimental campaign (see Chapter 6). The levels at which certain elements such as Ca and K occurred were very high and quite noticeable in the geochemical surveys conducted within a month of activities occurring. Calcium in particular at times measured more than 200000 ppm or 20% of the sample, a level which is almost an order of magnitude greater than the average measure of Ca in the Earth's crust (Salminen *et al.* 2005). Even at these pronounced concentrations, it is not known at what level these elements would need to be present to remain detectable over time, if at all. Further the behaviour of different elements can be greatly impacted by the makeup of those soils and sediments (Fijałkowski *et al.* 2012, Hooda 2010, Parton *et al.* 1988, Tiller 1989), as well as the vegetation that grows in them (Barber 1995, Adamczyk-Szabela *et al.* 2015). Potassium in particular has been studied due to its application in agriculture as a fertiliser. These studies however, generally focus on the reapplication of K products rather than simply studying the behaviour of the element in the soil independent of outside intervention (Beckett 1964, Ganeshamurthy and Biswas 1984). Calcium is not studied as an element that has been added to the soil except in the case of lime application, again in the purview of agriculture (Haynes and Naidu 1998). Some research has been done into the application of wood ash to soils as a fertiliser, which does have direct relevance to conditions under which both Ca and K are elevated in experimental metallurgical endeavours (Ohno and Susan Erich 1990, Demeyer *et al.* 2001) and these studies should be carefully examined for insights into how our longitudinal research should proceed.

Experimental metallurgical activities need to be carried out in multiple locations situated upon a variety of substrates in order to properly study the differences in the behaviour of elements introduced to the soils and sediments through the processes of metalworking. Further these experiments must be carried out not over a period of weeks but rather months and years to better understand how the geochemical signatures of these practices might change over time. At a minimum, a five year study should be conducted. Additionally if any of the sites where experimental work occurred previously are accessible and have not been subsequently utilised for other experimentation, they should be revisited every six months to add to the longitudinal dataset. In the case of previously utilised sites they should be examined at the same sampling resolution that was used at the time of the original experiments. All additional experiments would benefit from utilising a resolution of at 0.5x0.5m and ideally 0.25x0.25m dependent upon the size of the area under consideration. Though all samples were taken from the surface of the experimental areas for this study it is also prudent to consider collecting samples from multiple depths (*e.g.*, surface, 0.01m, 0.05m, 0.1m) in order to map the movement of elements in the soil matrix. Over time the experimental sites undergo taphonomic processes and may as a result become buried to some extent through the accumulation of leaf litter and other vegetal detritus as well as the movement of soils and sediments via erosion. At which time the surface that is being sampled may not be representative of the 'floor level' where experimental activities originally took place.

The second aspect to which future research needs to be devoted is in expanding the use of time-geography methods in concert with experimental production or the study of traditional practitioners. Informants are not capable of giving complete information as to their activities, and in some ways we are our own worst informants. In the course of experimental activities it is not difficult to forget all actions undertaken as well as the locations where specific processes occurred. By utilising cameras taking time-slice photographs to record the process of experimentation we are better equipped to later analyse the results of geochemical and geophysical survey of experimental areas. As was noted in this thesis, the number of individuals present during an experimental event can greatly impact the way in which the space is used and processes occur. Thus it seems prudent to experiment with varying the number of individuals involved in activities in order to better study how the number of participants impacts both the outcomes of the experimental process as well as the geochemical and geophysical signature produced on site. Additionally efforts should be made to study both 'enclosed' (*e.g.*, Experiment IV at Manor Park farm which was bounded by windbreaks to simulate an enclosed space) and 'unenclosed' to better consider the impact such boundedness has on the actions of the participants. These insights could then be applied when studying archaeological examples of metalworking that occurred either within or without structures.

Lastly, efforts need to be made to disseminate guidelines for *in situ* geochemical and geophysical study of metalworking contexts (see Appendix C) in order to potentially expand our dataset geographically and temporally. By contacting universities that have ready access to portable XRF and magnetic susceptibility probes we can begin to set up a network of specialists (and those in training) willing to work with local units to promptly and thoroughly examine metallurgical production contexts during the course of excavation. If we can change the current practice of excavation and its relationship with post-ex analysis we can expand the pool of data needed to embark on a better understanding of the spatial contexts of past metallurgical practices.

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Appendix A. Experimental Data

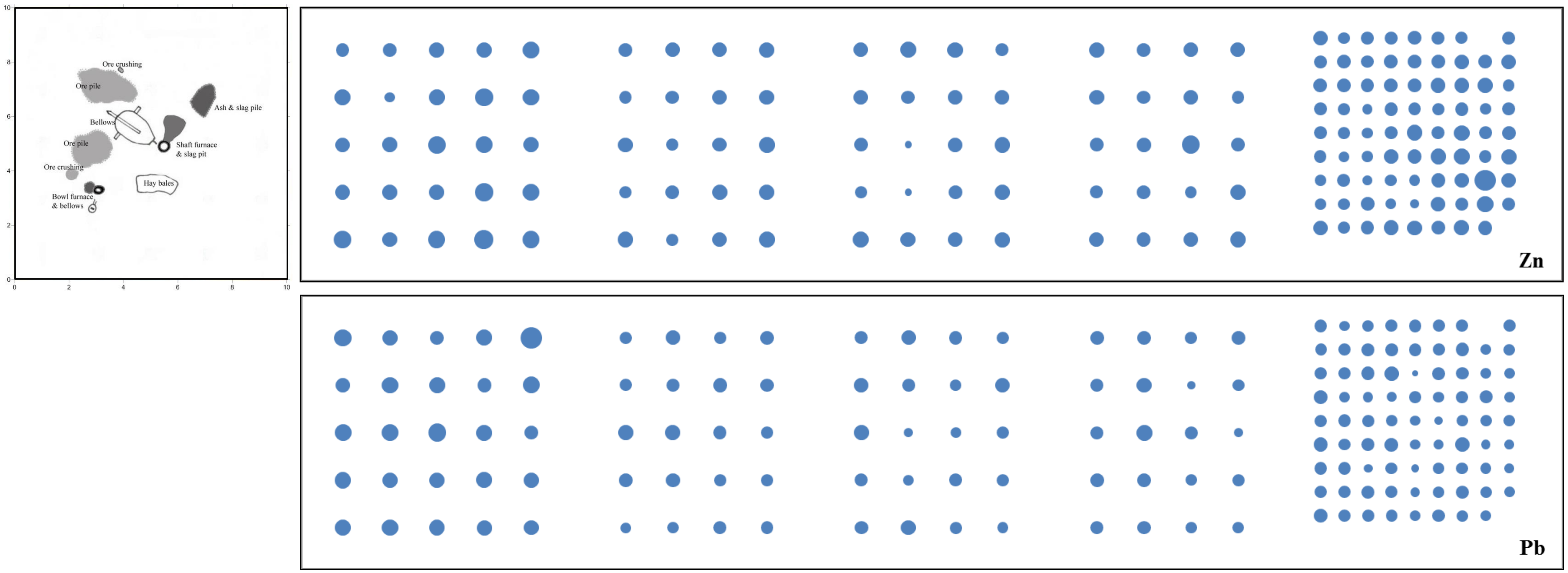


Figure A.1 Bubble plots of Zn and Pb concentrations from Experiment I Endcliffe Park, Sheffield alongside plan of site. ***From left to right:*** **Day0, Day3, Day4, Day5, and Day18.**

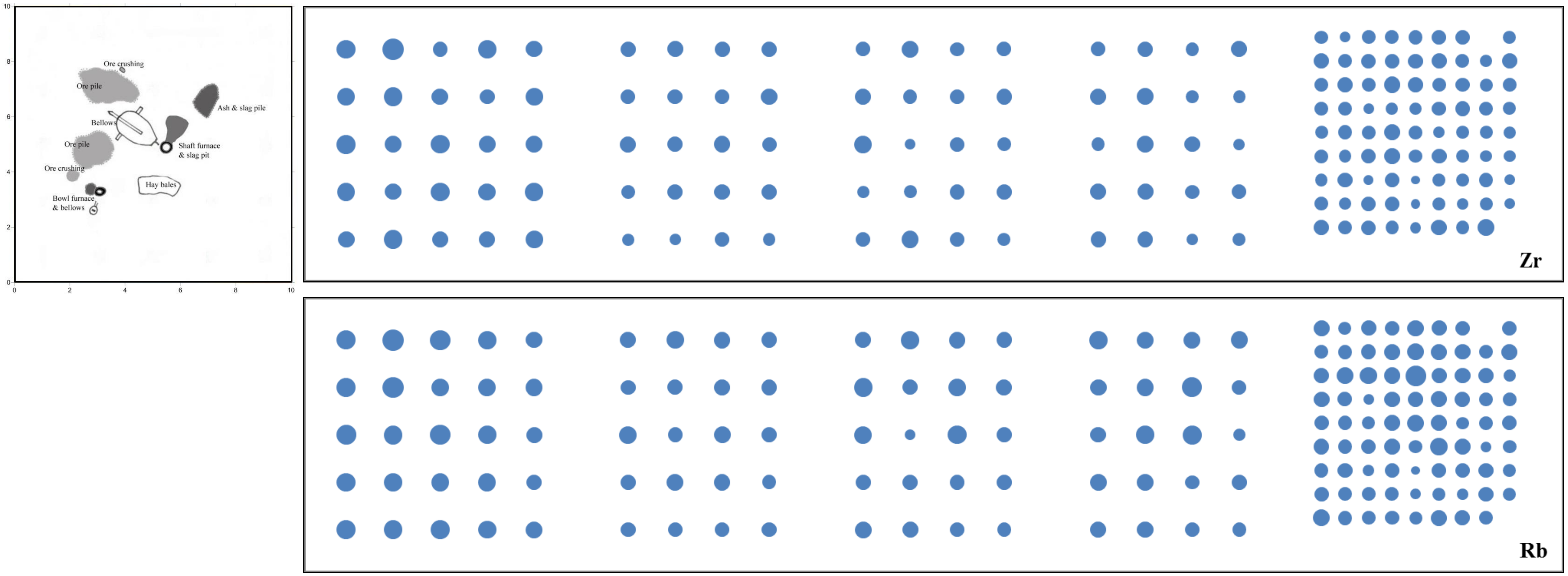


Figure A.2 Bubble plots of Zr and Rb concentrations from Experiment I Endcliffe Park, Sheffield alongside plan of site. ***From left to right:*** **Day0, Day3, Day4, Day5, and Day18.**

Table A.1 Experiment I - Ferrous Smithing pXRF and magnetic susceptibility data

Date	Easting	Northing	Zn	Zn Error	Pb	Pb Error	Zr	Zr Error	Rb	Rb Error	Fe	Fe Error	Mn	Mn Error	MagSus
Day0	1	1	91.72	16.07	193.04	16.16	255.59	11.17	39.22	4.61	26158	403.12	527.85	88.79	135
Day0	1	3	71.2	14.49	195.16	15.78	300.9	11.5	38.1	4.46	31939	431.44	476.39	84.56	136
Day0	1	5	68.22	14.72	202.58	16.53	339.27	12.41	42.18	4.76	28389	418.28	528.19	89.06	134
Day0	1	7	85.8	15.67	162.01	14.98	279.37	11.55	40.26	4.67	22871	375.72	480.24	84.65	155
Day0	1	9	56.86	13.77	205.86	16.4	314.61	11.92	40.51	4.57	29732	423.19	513.11	87.92	182
Day0	3	1	70.69	15.18	195.97	16.33	327.32	12.32	38.79	4.67	29787	430.07	594.99	93.56	133
Day0	3	3	71.06	14.27	165.99	14.86	240.38	10.67	35.76	4.36	25083	386.54	574.64	88.76	195
Day0	3	5	72.71	14.86	204.32	16.37	267.19	11.18	38.33	4.47	26692	401.18	546.67	88.31	227
Day0	3	7	32.08	14.57	194.82	17.22	311.36	12.74	47.66	5.35	56873	626.27	569.27	103.76	159
Day0	3	9	61.87	15.25	161.8	15.4	405.37	13.69	47.56	5.16	38439	499.46	571.14	96.96	170
Day0	5	1	90.32	15.17	168.61	14.47	239.43	10.36	37.25	4.3	24644	372.63	682.23	90.88	140
Day0	5	3	73.1	15.04	168.09	15.22	325.15	12.2	34.43	4.47	24540	390.25	508.47	87.49	167
Day0	5	5	97.74	16.98	228.43	17.51	317.72	12.2	43.83	4.9	35771	472.63	720.12	100.51	189
Day0	5	7	80.92	15.15	186.56	15.54	255.24	10.87	34.1	4.34	28868	412.13	634.55	92.65	194
Day0	5	9	73.06	15.02	135.56	13.83	205.04	10.31	44.18	4.8	28011	415.63	673.27	96.36	159
Day0	7	1	112.45	16.79	166.51	15.03	242.84	10.81	34.96	4.37	25199	390.65	807.8	100.75	168
Day0	7	3	104.65	16.45	186.19	15.6	270.81	11.16	34.7	4.33	25446	390.54	953.91	106.83	184
Day0	7	5	90.97	15.74	177.7	15.37	269.56	11.2	36.67	4.44	25524	392.71	731.75	96.96	161
Day0	7	7	103.07	15.52	138.3	13.35	212.36	9.88	32.67	4.13	21528	347.82	547.6	83.82	195
Day0	7	9	76.37	15.21	188.54	16.08	320.05	12.16	36.6	4.57	28685	422.19	781.03	101.78	160
Day0	9	1	91.42	15.2	162.95	14.37	280.54	10.97	30.18	4.03	21708	350.41	935.13	101.77	217
Day0	9	3	89.67	14.75	158.91	13.94	318.62	11.37	26.22	3.72	24364	365.39	793.38	94.86	157
Day0	9	5	69.52	13.49	134.75	12.86	244.4	10.16	27.4	3.72	19964	328.58	693.85	88.98	165
Day0	9	7	84.77	15.34	201.46	16.34	288.67	11.5	30.86	4.15	25454	392.13	728.51	97.23	152
Day0	9	9	91.39	15.57	313.94	19.45	241.78	10.61	28.96	4.05	23830	373.19	847.43	100.64	158
Day3	1	1	76.46	13.53	82.21	10.63	134.83	8.32	23.69	3.62	7439	204.53	202.77	57.36	118
Day3	1	3	49.44	12.16	127.47	12.75	167.34	9.05	24.46	3.7	16042	299.46	341.63	70.16	121
Day3	1	5	68	13.16	160.82	13.8	240.13	10.05	32.84	4	18826	316.78	321.72	68.02	99
Day3	1	7	49.86	11.5	105.29	11.2	193.72	8.99	23.69	3.44	14565	270.6	352.69	66.79	142
Day3	1	9	56.47	12.18	109.65	11.64	206.75	9.37	28.07	3.67	16059	288.98	391.24	70.29	126
Day3	3	1	47.56	10.74	95.87	10.42	118.84	7.46	21.81	3.25	12725	245.65	289.85	59.93	113
Day3	3	3	56.67	12.87	141.16	13.16	206.45	9.58	29.98	3.84	27410	383.27	467.43	79.21	128
Day3	3	5	44.63	12.32	165.79	14.69	205.12	9.93	23.55	3.81	19312	336.51	682.86	91.43	100
Day3	3	7	57.78	12.23	122.53	12.09	212.17	9.43	25.16	3.58	17307	298.62	325.89	67.18	123

Table A.1 Experiment I - Ferrous Smithing pXRF and magnetic susceptibility data

Date	Easting	Northing	Zn	Zn Error	Pb	Pb Error	Zr	Zr Error	Rb	Rb Error	Fe	Fe Error	Mn	Mn Error	MagSus
Day3	3	9	64.44	13.3	142.26	13.34	244.94	10.27	33.83	4.14	23614	359.28	472.52	79.52	205
Day3	5	1	67.91	13.15	127.54	12.59	188.83	9.27	24.16	3.58	15697	291.79	424.21	73.76	120
Day3	5	3	74.74	14.04	106.92	11.92	226.2	10.04	28.65	3.85	22509	353.38	622.05	87.05	132
Day3	5	5	63.43	13.58	128.68	13.25	247.42	10.68	31.13	4.18	20218	345.27	487.76	81.74	135
Day3	5	7	63.05	13.72	138.35	13.71	187.3	9.73	29.15	4.11	21945	360.89	472.43	82	146
Day3	5	9	66.5	13.76	109.46	12.26	207.8	9.92	29.17	4.03	19836	338.15	408.45	76.86	158
Day3	7	1	81	12.8	108.52	11.01	151.46	8.03	23.56	3.3	13536	253.83	523.25	73.03	117
Day3	7	3	71.11	12.99	109.34	11.51	219.39	9.52	22.05	3.5	15431	283.48	479.42	74.92	116
Day3	7	5	80.54	13.44	104.08	11.28	193.67	9.1	26.66	3.64	15965	286.86	533.95	77.38	181
Day3	7	7	67.55	13.5	127.56	12.8	243.57	10.31	26.27	3.74	20443	336.99	671.73	88.6	183
Day3	7	9	74.05	14.03	136.42	13.3	219.81	10.07	26.98	3.9	22533	358.13	497.1	81.51	145
Day4	1	1	78.74	14.5	129.62	13.17	200.17	9.84	30.54	4.07	20174	342.92	473.88	80.88	121
Day4	1	3	45.7	11.3	116.21	11.65	144.58	8.18	24.31	3.51	15118	276.09	279.77	63.39	119
Day4	1	5	57.28	13.44	160.03	14.59	279.9	11.27	33.06	4.31	22655	367.53	469.58	82.31	127
Day4	1	7	68.92	14.47	148.5	14.42	227.88	10.64	37.3	4.51	22280	371.01	449.81	82.51	165
Day4	1	9	68.8	13.07	118.86	11.97	197.41	9.25	28.19	3.76	17338	300.62	325.98	67.42	136
Day4	3	1	70.75	13.78	155.54	13.87	270.33	10.74	28.13	3.88	21205	343.28	426.77	76.35	265
Day4	3	3	16	23.61	84.38	13.23	158.92	10.95	24.73	4.66	130822	1037.58	834.25	145.74	147
Day4	3	5	16	26.91	61.9	12.94	100.73	10.74	12.61	4.34	144914	1173.21	5080.07	295.8	106
Day4	3	7	58.99	12.62	120.88	12.1	181.2	9.02	25.11	3.62	19975	323.4	382.76	71.08	132
Day4	3	9	82.05	14.97	149.68	14.19	263.99	11.04	35.44	4.42	22292	364.14	424.18	79.87	150
Day4	5	1	66.93	13.05	104.96	11.48	204.79	9.4	23.02	3.52	19242	317.97	457.28	75.53	105
Day4	5	3	59.02	12.86	118.72	12.16	210.4	9.58	24.56	3.57	22970	349.6	483.51	78.38	153
Day4	5	5	66.46	13.85	80.76	11.1	196.28	9.87	37.28	4.46	20479	348.46	446.19	80.11	147
Day4	5	7	67.02	14.17	87.5	11.61	188.26	9.88	34.79	4.4	21539	361.98	329.02	74.47	186
Day4	5	9	75.02	13.36	131.1	12.46	179.14	8.93	30.11	3.81	22093	336.35	538.32	79.26	169
Day4	7	1	72.82	12.7	88.78	10.46	156.4	8.33	21.45	3.33	15546	278.34	444.19	71.61	103
Day4	7	3	78.26	13.04	102.8	11.06	201.92	9.08	23.49	3.43	14126	266.11	410.84	69.7	170
Day4	7	5	78.79	14.05	104.44	11.84	172.43	9.14	23.53	3.66	16970	308	496.78	79.05	128
Day4	7	7	65.9	13.24	148.92	13.32	232.35	9.91	27.66	3.78	23066	349.59	640.85	86.34	154
Day4	7	9	53.72	12.84	105.95	11.99	193.58	9.58	26.52	3.83	16380	306.31	429.8	76.01	151
Day5	1	1	66.31	13.57	126.85	13.04	218.32	10.12	28.81	3.97	17150	315.27	437.41	77.49	158
Day5	1	3	51.59	12.6	132.84	13.18	233.71	10.29	29.7	4.05	20333	340.82	498.3	80.66	129
Day5	1	5	59.29	12.93	123.17	12.63	162.76	9	26.63	3.82	18360	319.95	432.57	76	122

Table A.1 Experiment I - Ferrous Smithing pXRF and magnetic susceptibility data

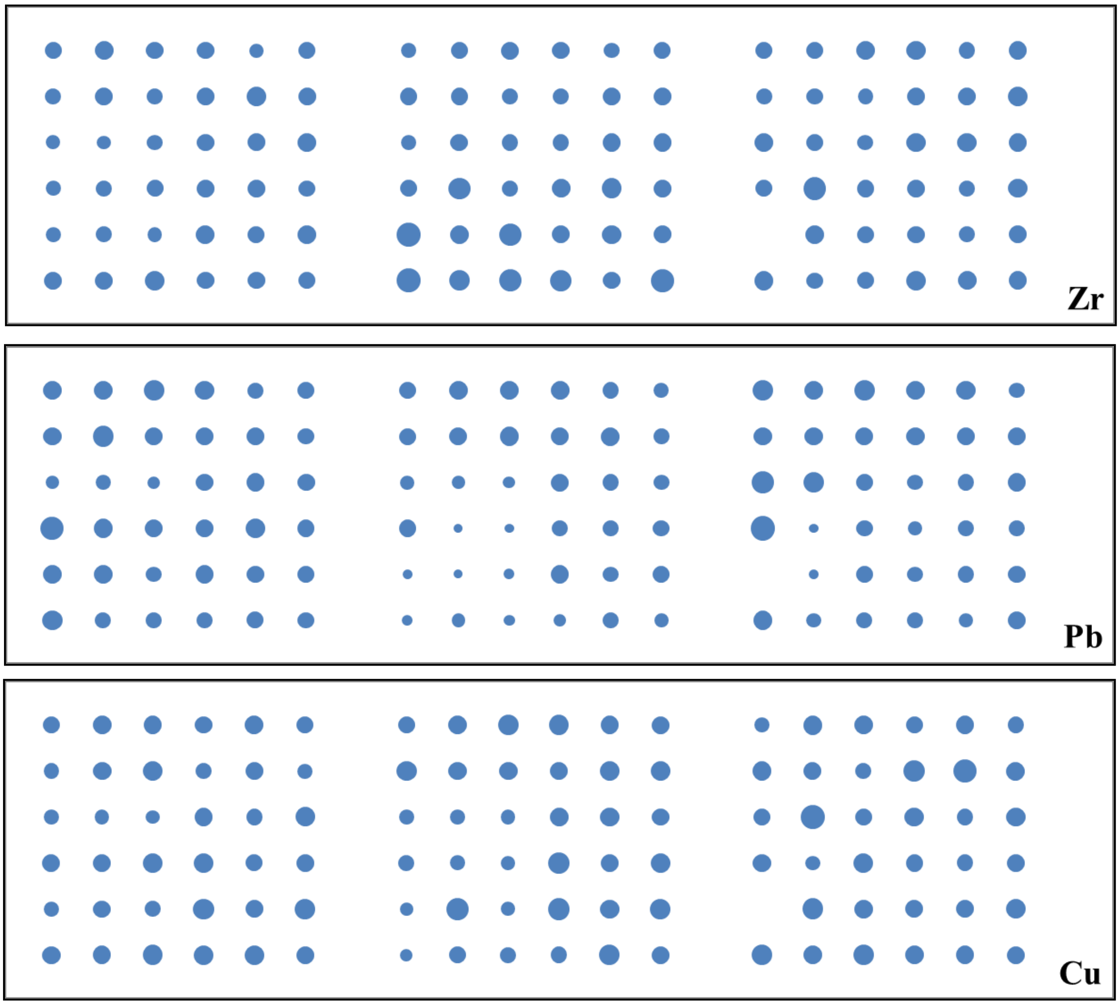
Date	Easting	Northing	Zn	Zn Error	Pb	Pb Error	Zr	Zr Error	Rb	Rb Error	Fe	Fe Error	Mn	Mn Error	MagSus
Day5	1	7	70.59	13.82	125.84	12.94	223.87	10.18	29.44	4.08	17968	322.19	461.39	79.13	203
Day5	1	9	72.94	14.35	136.89	13.53	191.19	9.76	36.27	4.36	20478	346.7	415.84	78.15	131
Day5	3	1	61.02	13.02	131.93	13.05	217.29	9.95	28.27	3.86	17465	313.54	397.17	74.22	120
Day5	3	3	61.22	15.09	140.25	14.01	234.49	10.74	29.95	4.15	51795	561.63	718.52	103.72	133
Day5	3	5	67.33	15.03	183.08	16.02	256.04	11.32	34.65	4.49	31155	446.28	1140.68	119.46	133
Day5	3	7	56.62	13.23	156.2	14.33	258.29	10.84	30.95	4.12	20925	350.45	454.43	80.98	119
Day5	3	9	58.87	12.5	134.48	12.78	209.36	9.5	31	3.88	20950	331.32	432.85	74.75	171
Day5	5	1	66.75	12.12	101.53	10.87	133.31	7.83	21.05	3.29	12418	247.32	459.82	70.94	135
Day5	5	3	43.91	11.48	91.47	10.88	177.93	8.93	21.98	3.47	21067	331.45	434.16	74.89	214
Day5	5	5	102.92	16.2	119.7	12.96	218.01	10.35	39.49	4.56	22325	366.58	704.55	94.76	162
Day5	5	7	71.73	14.07	47.97	9.14	168.01	9.26	42.45	4.55	15767	303.03	332.16	71.26	83
Day5	5	9	68.97	13.01	105.42	11.29	167.74	8.62	30.43	3.78	21113	326.27	492.1	76.45	166
Day5	7	1	76.63	13.18	90.85	10.7	156.39	8.48	21.77	3.39	13581	265.03	404.16	69.82	215
Day5	7	3	74.64	13.09	106.55	11.3	192.59	9.02	24.12	3.5	16041	286.12	682.42	84.34	122
Day5	7	5	61.46	11.46	59.74	8.61	118.16	7.31	15.05	2.84	12407	239.74	335.08	61.75	140
Day5	7	7	50.91	11.39	98.48	10.72	146.22	8.07	22.35	3.28	14713	268.84	331.3	64.36	141
Day5	7	9	68.33	14.04	128.09	13.19	231.29	10.37	31.95	4.11	23752	371.25	563.92	86	140
Day18	0.5	1.5	66.32	12.91	137.03	12.74	204.03	9.35	29.49	3.8	17800.45	304.5	407.86	71.98	106
Day18	0.5	2.5	39.24	10.29	105.8	10.8	176.59	8.38	23.84	3.3	15070.44	265.65	361.95	64.37	60
Day18	0.5	3.5	42.61	10.39	109.23	10.89	139.97	7.73	21.19	3.26	10969.52	226.65	244.64	55.88	59
Day18	0.5	4.5	49.33	11.35	138.47	12.62	173.96	8.74	26.21	3.59	14079.99	268.56	397.68	69.31	58
Day18	0.5	5.5	51.19	11.2	106.14	11.02	151.19	8.11	21.86	3.3	13074.98	251.75	262.1	59.62	82
Day18	0.5	6.5	52.69	11.74	131.92	12.33	181.42	8.83	27.03	3.63	14963.04	275.82	333.99	65.94	74
Day18	0.5	7.5	58.78	12.08	107.16	11.37	171.41	8.72	24.64	3.53	13881.66	267.12	286.59	62.95	98
Day18	0.5	8.5	54.34	12.59	99.01	11.8	209.14	9.93	21.06	3.62	13797.99	283.7	272.51	66.61	68
Day18	0.5	9.5	65.32	12.47	111.28	11.47	166.62	8.56	27.34	3.61	14580.67	271.5	311.37	64.66	91
Day18	1.5	1.5	46.44	11.33	102.71	11.27	172.91	8.78	22.09	3.46	13089.65	261.7	351.13	67.24	75
Day18	1.5	2.5	42.12	11.12	100.8	11.15	138.18	8.16	20.07	3.37	14373.8	272.85	282.8	63.58	79
Day18	1.5	3.5	53.48	12.15	114.37	11.91	203.18	9.41	24.68	3.67	17530.29	304.32	398.5	71.86	80
Day18	1.5	4.5	36.27	10.45	100.74	10.94	145.12	8.11	21.88	3.31	12104.5	246.58	229.22	58.23	204
Day18	1.5	5.5	47.2	11.07	116.61	11.4	187.43	8.71	22.31	3.35	14272.58	263.45	248.66	59	71
Day18	1.5	6.5	42.71	10.6	87.71	10.24	164.49	8.33	22.55	3.28	13827.97	259.03	228.3	57.31	91
Day18	1.5	7.5	60.06	12.45	116.55	12.02	199.39	9.32	29.21	3.77	17308.73	301.57	236.16	62.13	100
Day18	1.5	8.5	61.44	12.38	104.65	11.33	162.65	8.6	22	3.4	15675.53	284.84	327.05	66.11	78

Table A.1 Experiment I - Ferrous Smithing pXRF and magnetic susceptibility data

Date	Easting	Northing	Zn	Zn Error	Pb	Pb Error	Zr	Zr Error	Rb	Rb Error	Fe	Fe Error	Mn	Mn Error	MagSus
Day18	1.5	9.5	43.87	10.45	76.17	9.56	107.74	7.23	18.02	3.09	12940.18	246.94	230.05	56.32	84
Day18	2.5	1.5	55.49	12.22	107.3	11.78	190.22	9.3	20.71	3.47	13969.05	277.25	278.29	64.21	77
Day18	2.5	2.5	59.19	12.43	113.67	11.8	185.32	9.07	20.56	3.42	17807.76	306.08	265.81	63.98	106
Day18	2.5	3.5	33.99	12.91	57.14	9.72	81.25	7.59	13.54	3.24	46742.26	525.63	342.18	81.58	185
Day18	2.5	4.5	42.74	11.07	121.51	11.83	184.67	8.81	21.67	3.33	14709.55	272.01	300.57	63.46	199
Day18	2.5	5.5	37.69	11.04	103.22	11.31	169.59	8.73	19.27	3.29	19264.37	314.86	405.9	71.74	80
Day18	2.5	6.5	33.58	10.54	74.32	9.77	108.15	7.48	11.97	2.89	21350.52	326.87	301.37	65.51	724
Day18	2.5	7.5	55.82	11.92	127.66	12.01	178.03	8.68	32.32	3.82	17145.53	291.16	376.63	68.1	193
Day18	2.5	8.5	49.62	11.82	116.81	11.9	190.04	9.1	23.86	3.6	17392.09	301.22	342.26	67.92	120
Day18	2.5	9.5	49.38	11.61	94.85	10.8	168.44	8.64	24.51	3.48	17059.99	294.69	347.33	67.76	129
Day18	3.5	1.5	70.23	13.24	97.96	11.34	166.32	8.89	21.6	3.46	13591.11	273.26	426.2	73.36	73
Day18	3.5	2.5	36.05	10.97	106.92	11.43	181.67	8.9	20.19	3.36	23740.51	349.13	469.1	75.84	345
Day18	3.5	3.5	45.15	12.67	103.7	11.72	201.72	9.65	23.79	3.74	32477.44	423.47	659.51	90.85	154
Day18	3.5	4.5	69.85	13.01	132.98	12.51	242.48	9.91	26.7	3.64	18173.67	306.39	437.44	73.53	120
Day18	3.5	5.5	50.68	11.84	99.27	11.17	237.01	9.83	28.17	3.73	17249.28	298.48	400.79	71.47	145
Day18	3.5	6.5	56.72	12.09	70.66	9.82	142.03	8.27	26.25	3.63	13080.97	261.17	221.18	59.18	188
Day18	3.5	7.5	61.29	13.46	150.46	14.06	241.65	10.54	28.64	4.02	19265.34	335.34	397.67	76.59	167
Day18	3.5	8.5	58.29	11.88	120.48	11.88	190.52	8.96	28.05	3.71	14138.11	267.18	306.31	63.79	162
Day18	3.5	9.5	53.87	11.91	104.56	11.27	174.35	8.76	23.33	3.39	17678.75	300.46	359.99	68.15	159
Day18	4.5	1.5	68.03	11.76	82.2	9.7	118.3	7.31	18.16	3.04	10520.04	221.31	304.94	59.99	79
Day18	4.5	2.5	25.15	9.46	64.18	9.35	86.25	7.06	13.03	2.94	8615.7	212.85	168.51	53.68	103
Day18	4.5	3.5	41	9.7	45.98	7.77	73.35	6.3	8.83	2.5	9203.38	202.83	232.9	53.38	99
Day18	4.5	4.5	64	12	78.48	9.81	164.81	8.32	19.82	3.21	12846.92	250.63	370.44	66.06	129
Day18	4.5	5.5	79.88	14.25	74.73	10.51	171.28	9.28	31.18	4.06	14467.91	289.56	478.31	78.53	433
Day18	4.5	6.5	51.83	11.72	100.74	11.06	131.98	7.99	24.73	3.52	17756.2	299.94	440.16	72.6	142
Day18	4.5	7.5	56.6	12.9	28.55	7.77	194.92	9.58	45.88	4.63	18059.86	318.6	306.1	68.9	93
Day18	4.5	8.5	60.12	12.69	118.37	12.08	197.01	9.34	31.27	3.94	18742.06	315.13	412.1	73.3	148
Day18	4.5	9.5	58.81	12.46	111.97	11.62	182.71	8.95	29.26	3.78	20083.91	320.18	393.56	71.19	138
Day18	5.5	1.5	56.99	12.67	112.95	12.13	223.09	9.98	27.16	3.76	15205.2	292.28	448.88	76.15	69
Day18	5.5	2.5	67.23	12.19	91.85	10.54	152.97	8.22	18.94	3.16	12793.18	252.05	441.76	69.83	82
Day18	5.5	3.5	60.29	12.18	93.58	10.89	161.43	8.56	23.94	3.45	13648.42	266.17	372.08	68.27	164
Day18	5.5	4.5	74.84	13.78	70.45	10.08	206.24	9.69	34.57	4.13	18386.39	317.75	381.21	72.8	962
Day18	5.5	5.5	50.16	12.56	54.46	9.5	124.09	8.46	28.78	4	13758.48	284.35	293.69	67.87	591
Day18	5.5	6.5	47.87	11.2	87.22	10.36	182.07	8.75	27.73	3.6	15033.45	272.96	406.02	69.27	299

Table A.1 Experiment I - Ferrous Smithing pXRF and magnetic susceptibility data

Date	Easting	Northing	Zn	Zn Error	Pb	Pb Error	Zr	Zr Error	Rb	Rb Error	Fe	Fe Error	Mn	Mn Error	MagSus
Day18	5.5	7.5	67.35	12.83	118.54	11.9	173.53	8.79	24.2	3.5	17397.3	300.32	714.64	86.72	165
Day18	5.5	8.5	57.97	12.07	102.66	11.19	212.9	9.35	26.76	3.66	17090.54	294.1	334.38	66.77	151
Day18	5.5	9.5	52.1	11.51	105.2	11.18	186.84	8.88	24.53	3.47	16279.71	285.9	472.24	73.5	162
Day18	6.5	1.5	74.15	12.86	90.03	10.55	167.26	8.54	24.64	3.53	15538.86	278.76	498.35	74.79	109
Day18	6.5	2.5	53.81	10.37	114.95	10.65	115.68	7	14	2.69	10991.07	217.88	457.33	65.24	80
Day18	6.5	3.5	67.34	12.08	103.82	10.85	158.2	8.18	21.8	3.22	14255.08	261.68	429.29	68.83	106
Day18	6.5	4.5	77.77	13.42	140.22	12.76	150.93	8.4	28.78	3.71	17125.48	297.37	548.05	78.5	87
Day18	6.5	5.5	75.69	12.89	89.82	10.59	147.6	8.28	16.97	3.19	11629.86	245.67	444.92	70.94	124
Day18	6.5	6.5	56.6	12.18	103.57	11.34	208.9	9.39	24.9	3.56	13962.05	270.88	523.35	76.75	105
Day18	6.5	7.5	71.77	12.83	117.49	11.74	179.14	8.77	26.68	3.57	17919.18	299.99	385.18	69.41	106
Day18	6.5	8.5	64.78	12.78	126.57	12.31	175.33	8.89	26.4	3.68	18492.45	311.3	449.05	74.62	111
Day18	6.5	9.5	47.15	11.42	104.29	11.24	182.68	8.87	21.22	3.4	15311.4	279.92	338.43	66.8	112
Day18	7.5	1.5	38.04	10.08	64.54	9.03	147.83	7.96	16.61	3.01	8854.47	207.64	272.83	57.9	78
Day18	7.5	2.5	83.32	13.9	92.65	10.92	154.31	8.53	23.49	3.5	17320.64	301.68	591.93	81.99	158
Day18	7.5	3.5	139.2	17.6	82.72	11.09	187.67	9.69	23.91	3.79	20748.41	347.45	1016.26	106.62	210
Day18	7.5	4.5	51.91	10.73	66.51	9.06	130.19	7.58	12.57	2.78	7246.69	187.36	252.95	55.88	87
Day18	7.5	5.5	52.49	11.13	94.66	10.44	152.79	8.06	19.88	3.15	12576.88	245.88	403.13	66.95	93
Day18	7.5	6.5	41.97	11.73	121.72	12.46	158.86	8.83	18.77	3.34	12977.83	270.33	436.92	75.02	93
Day18	7.5	7.5	68.09	13.14	77.63	10.32	154.63	8.63	23.62	3.61	18460.69	313.79	785.22	91.32	137
Day18	7.5	8.5	57.81	12.5	87.59	10.88	138.26	8.38	19.01	3.39	15316.53	289.68	420.32	73.35	95
Day18	8.5	1.5	64.54	11.87	89.63	10.28	242.44	9.5	20.07	3.21	11462.86	236.32	441.47	68.97	111
Day18	8.5	2.5	55.18	11.95	80.85	10.12	104.96	7.47	17.81	3.18	12905.13	257.27	533.92	76.04	89
Day18	8.5	3.5	67.8	12.11	73.51	9.5	103.1	7.21	19.08	3.13	11775.38	238.91	333.64	62.88	129
Day18	8.5	4.5	73.28	12.99	71.19	9.72	128.67	7.87	19.2	3.29	14199.33	269.19	467.74	73.27	130
Day18	8.5	5.5	61.69	12.31	95.1	10.74	133.03	7.96	23.62	3.44	13855.93	265.32	411.89	70.18	112
Day18	8.5	6.5	52.08	11.51	85.01	10.3	157.68	8.34	21.19	3.34	11752.72	244.11	414.88	68.84	133
Day18	8.5	7.5	41.89	10.83	83.99	10.14	181.97	8.69	16.28	3.12	12437.84	249.36	347.42	65.08	80
Day18	8.5	8.5	65.13	12.71	95.03	10.89	217.76	9.49	27.94	3.67	16678.75	293.87	655.14	83.73	88
Day18	8.5	9.5	51.72	11.82	105.96	11.43	159.93	8.56	21.74	3.42	14763.3	277.74	388.21	70.24	125



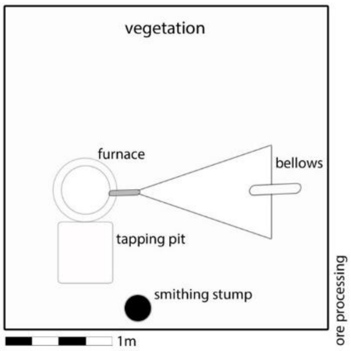
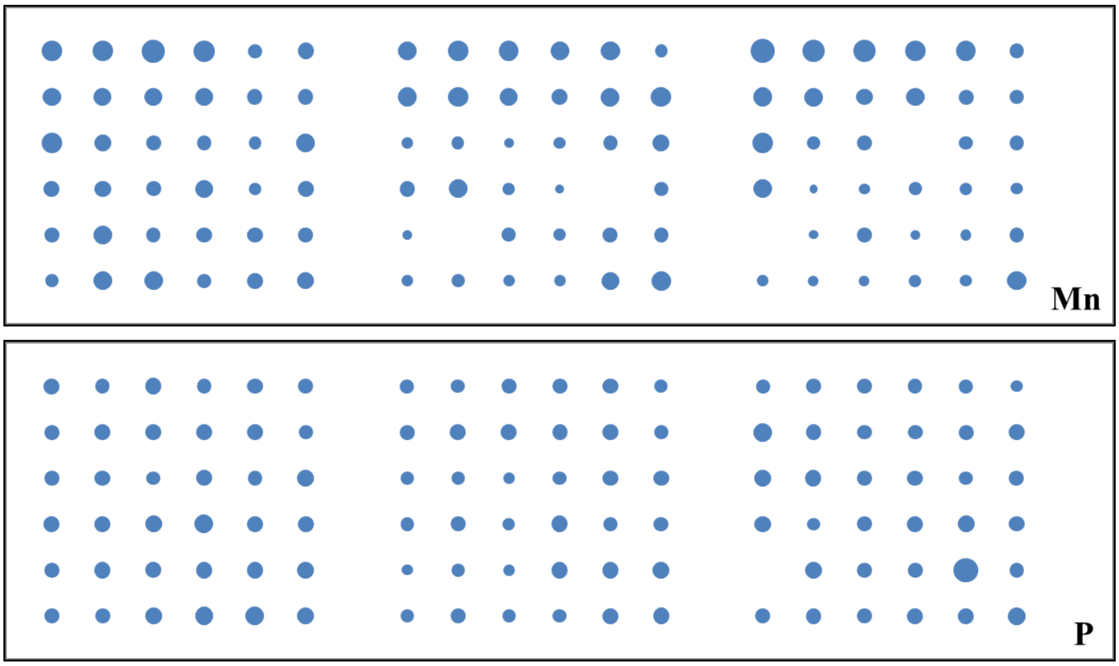


Figure A.3 Bubble plots of Zr, Pb, and Cu concentrations from Experiment III Site A, Ecclesall Woods, Sheffield alongside plan of site. ***From left to right:*** **26Oct, 9Nov, and16Nov.**



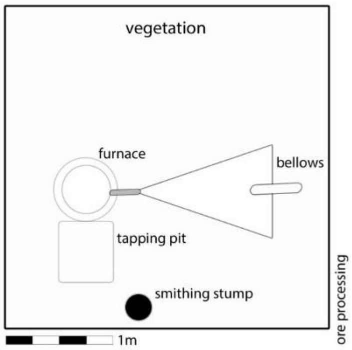


Figure A.4 Bubble plots of Mn, and P concentrations from Experiment III Site A, Ecclesall Woods, Sheffield alongside plan of site. ***From left to right:*** **26Oct, 9Nov, and16Nov.**

Table A.2 Experiment III - Ferrous Smithing pXRF and magnetic susceptibility data

Date	Easting	Northing	Zr	Zr Error	Sr	Sr Error	Rb	Rb Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Ca	Ca Error	K	K Error	P	P Error	MagSus
26-Oct	0.25	0.25	98.29	2.67	72.04	2.10	29.75	1.31	325.95	11.49	133.08	9.75	184.58	15.56	54044	360.2	412.00	69.66	14499	320.0	7771	275.89	1910	171.2	683
26-Oct	0.25	0.75	68.08	2.21	61.28	1.86	26.39	1.19	302.16	10.62	149.52	9.78	124.67	13.61	43792	308.6	557.17	69.50	21492	364.6	7293	260.88	1959	167.3	634
26-Oct	0.25	1.25	71.97	2.32	64.15	1.95	25.45	1.20	447.48	13.05	163.53	10.40	173.68	15.13	57055	367.7	622.63	72.37	20626	361.4	7179	261.61	2156	175.6	462
26-Oct	0.25	1.75	63.44	2.01	55.31	1.67	18.79	1.00	157.68	7.53	188.99	10.09	124.94	12.79	31046	240.3	1006.34	73.30	27013	380.7	5949	226.83	1995	169.9	244
26-Oct	0.25	2.25	78.99	2.49	67.96	2.08	25.90	1.25	275.83	10.83	148.55	10.34	129.83	14.57	52150	358.9	797.14	78.20	21214	364.1	7134	260.50	1883	164.3	810
26-Oct	0.25	2.75	92.21	2.63	67.34	2.06	27.90	1.29	280.66	10.93	189.98	11.33	157.44	15.21	47459	344.1	1039.10	83.19	31351	430.7	7490	267.77	2097	177.2	571
26-Oct	0.75	0.25	96.24	2.87	120.34	2.83	19.53	1.16	202.48	9.79	154.16	10.86	186.28	16.66	56536	389.2	813.14	81.21	23143	387.1	5666	242.34	1800	171.7	760
26-Oct	0.75	0.75	79.71	2.60	79.90	2.31	29.87	1.37	291.75	11.42	165.11	10.99	169.81	15.92	61211	404.9	841.05	81.06	20540	371.3	7021	266.90	2244	171.1	1372
26-Oct	0.75	1.25	80.99	2.60	78.48	2.27	28.45	1.34	294.23	11.42	166.86	11.09	168.76	16.10	60756	406.3	663.88	77.91	23679	401.8	7720	283.83	2018	177.0	909
26-Oct	0.75	1.75	59.26	1.99	51.34	1.64	21.32	1.03	188.19	8.21	196.17	10.33	115.28	12.73	39082	274.6	685.77	68.25	22251	356.2	6139	233.41	2043	169.4	338
26-Oct	0.75	2.25	95.71	2.83	67.27	2.18	32.98	1.47	355.67	12.85	239.04	13.13	189.31	17.09	63511	428.5	802.33	83.08	16313	361.5	8189	304.14	2027	175.9	728
26-Oct	0.75	2.75	107.86	2.98	73.74	2.28	32.62	1.46	277.37	11.50	198.13	12.16	194.36	17.16	64259	435.1	985.73	86.83	28909	440.7	7956	288.98	1733	181.2	591
26-Oct	1.25	0.25	119.46	3.21	107.11	2.77	23.07	1.29	210.89	10.35	142.94	11.04	227.54	18.29	75238	484.4	833.52	84.91	19918	396.0	6486	275.86	2345	186.5	3153
26-Oct	1.25	0.75	67.15	2.33	73.30	2.12	23.25	1.18	207.90	9.41	141.15	9.97	146.22	14.75	53536	358.5	526.42	71.98	19673	361.1	6308	253.33	2053	162.6	893
26-Oct	1.25	1.25	87.00	2.65	77.92	2.25	26.41	1.29	260.88	10.77	158.43	10.81	223.59	17.13	67074	428.9	555.30	75.61	18489	375.9	7081	280.38	2332	172.4	1286
26-Oct	1.25	1.75	73.35	2.27	54.93	1.79	30.06	1.26	128.89	7.48	170.11	10.32	109.82	13.34	37479	283.9	560.11	70.30	21255	344.8	5141	212.74	1614	151.8	441
26-Oct	1.25	2.25	85.68	2.66	70.69	2.18	27.97	1.34	264.85	10.97	172.83	11.23	209.53	16.94	58885	398.1	808.50	80.98	21986	386.0	7414	275.51	2219	175.2	752
26-Oct	1.25	2.75	93.08	2.66	70.50	2.11	29.28	1.33	341.39	11.97	221.80	12.06	190.55	16.07	50228	356.3	1307.29	87.93	29859	432.3	7968	280.68	2260	180.3	779
26-Oct	1.75	0.25	90.58	2.84	91.09	2.53	21.87	1.25	229.44	10.63	115.09	10.18	216.68	17.70	78983	492.4	478.25	77.71	13080	329.7	6149	267.38	2729	172.7	1549
26-Oct	1.75	0.75	108.56	3.15	112.33	2.87	23.21	1.31	272.16	11.71	127.73	10.82	237.06	18.76	87031	535.8	559.62	80.86	14134	354.7	6277	281.86	2291	175.6	1719
26-Oct	1.75	1.25	91.46	2.79	106.17	2.66	23.31	1.24	238.11	10.52	150.04	10.85	213.82	17.13	69093	441.0	720.98	79.56	17090	354.6	6275	261.48	2882	180.2	1415
26-Oct	1.75	1.75	94.77	2.84	89.36	2.47	26.98	1.34	237.38	10.63	131.47	10.47	185.95	16.79	70909	454.6	535.37	77.43	13114	325.6	7282	283.24	2108	172.4	1293
26-Oct	1.75	2.25	106.83	2.93	77.28	2.30	27.07	1.33	265.73	11.11	165.81	11.23	158.69	16.14	68293	445.2	709.65	80.63	27836	440.9	7162	282.51	1926	181.6	799
26-Oct	1.75	2.75	94.80	2.78	74.69	2.25	32.91	1.44	304.47	11.75	186.13	11.68	169.26	16.37	59825	408.6	1105.70	87.23	27567	432.8	7787	289.34	1745	190.2	832
26-Oct	2.25	0.25	92.58	2.77	85.47	2.40	25.20	1.29	234.88	10.48	149.48	10.80	211.43	17.11	64556	424.7	592.85	77.67	13543	322.3	6016	254.36	2907	175.4	1255
26-Oct	2.25	0.75	89.66	2.64	75.59	2.19	25.01	1.24	251.76	10.49	153.45	10.60	176.04	15.83	60673	397.7	580.45	75.19	15965	341.2	6437	263.88	2261	171.3	1008
26-Oct	2.25	1.25	96.41	2.85	75.70	2.30	31.48	1.44	306.41	12.01	145.94	10.87	164.36	16.39	69469	452.3	348.82	74.59	11699	325.0	8166	305.90	2139	185.8	1361
26-Oct	2.25	1.75	98.15	2.77	70.52	2.15	29.00	1.34	265.82	10.89	119.23	9.84	147.19	15.40	59224	394.2	405.53	72.50	13396	323.7	7675	283.44	1760	175.4	1141
26-Oct	2.25	2.25	112.18	3.01	83.56	2.39	31.07	1.42	258.32	11.00	142.42	10.72	175.73	16.54	66530	435.8	571.80	78.03	14359	341.1	7339	287.56	2022	172.8	1267
26-Oct	2.25	2.75	64.66	2.19	62.23	1.89	23.24	1.14	206.02	9.06	169.88	10.34	200.25	15.37	47543	326.3	485.21	68.96	26376	398.9	6235	247.51	1966	170.8	666
26-Oct	2.75	0.25	91.35	2.86	88.78	2.52	25.33	1.33	223.36	10.58	166.15	11.55	183.12	17.17	75778	484.8	693.71	82.27	14176	344.8	6800	283.18	2220	172.3	1587
26-Oct	2.75	0.75	104.98	3.04	89.52	2.55	27.29	1.39	248.00	11.22	125.87	10.70	233.95	18.44	71792	471.4	558.70	80.47	11370	311.7	7135	279.86	2265	177.8	1234
26-Oct	2.75	1.25	84.43	2.66	81.37	2.33	26.41	1.30	247.56	10.65	150.43	10.67	170.56	16.13	70172	440.6	635.32	77.31	15129	337.9	7171	275.70	2067	174.6	1249
26-Oct	2.75	1.75	112.55	3.21	93.02	2.66	26.85	1.41	250.31	11.49	166.32	12.01	215.85	18.57	80431	520.8	820.75	87.34	19033	398.4	7197	297.26	2293	187.3	1333
26-Oct	2.75	2.25	95.72	2.71	74.93	2.18	27.12	1.29	224.53	10.00	177.55	11.11	129.61	14.87	59002	392.3	566.46	75.00	19930	371.6	7610	281.65	1622	175.3	1121
26-Oct	2.75	2.75	89.45	2.74	89.91	2.45	28.42	1.35	238.58	10.54	150.47	10.78	159.05	15.88	63822	421.7	638.24	78.33	16831	351.8	7491	280.71	1995	175.6	997
09-Nov	0.25	0.25	179.47	3.54	54.90	1.91	43.23	1.59	92.77	7.17	127.84	9.99	87.31	13.96	47553	348.8	331.60	71.43	8365	278.5	12659	347.11	1413	196.6	727
09-Nov	0.25	0.75	186.45	3.63	55.72	1.94	43.66	1.61	74.75	6.72	110.29	9.65	103.45	14.56	38898	314.2	214.85	69.17	9279	276.2	13554	345.12	1001	190.9	193
09-Nov	0.25	1.25	90.04	2.50	54.75	1.82	31.14	1.31	247.43	9.98	186.54	10.91	144.68	14.49	40874	303.6	587.75	71.98	19202	345.4	9284	287.34	1520	173.7	386
09-Nov	0.25	1.75	73.02	2.27	51.66	1.74	17.88	1.02	167.39	8.28	91.08	8.33	126.80	13.53	44435	311.0	294.76	64.78	14063	295.5	5915	229.10	1433	142.0	
09-Nov	0.25	2.25	91.14	2.73	89.83	2.42	26.70	1.30	234.46	10.33	144.72	10.61	219.24	17.16	55077	382.0	890.76	82.14	17746	353.3	6899	265.86	1899	173.4	690
09-Nov	0.25	2.75	70.05	2.28	60.73	1.90	24.89	1.19	243.02	9.88	158.19	10.22	167.12	14.83	41390	304.7	838.39	76.50	26277	387.5	6883	250.45	1662	166.0	529
09-Nov	0.75	0.25	130.86	3.19	74.19	2.25	38.41	1.55	150.22	8.76	199.62	12.06	158.32	16.19	59445	407.5	431.20	74.95	19753	394.9	12308	362.17	1814	198.5	823

Table A.2 Experiment III - Ferrous Smithing pXRF and magnetic susceptibility data

Date	Easting	Northing	Zr	Zr Error	Sr	Sr Error	Rb	Rb Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Ca	Ca Error	K	K Error	P	P Error	MagSus
09-Nov	0.75	0.75	105.20	3.16	110.55	2.91	37.56	1.63	64.92	6.95	42.61	8.39	269.92	19.93	91498	565.7	< LOD	148.47	7726	300.3	9667	344.19	1517	178.1	5284
09-Nov	0.75	1.25	147.95	3.56	62.47	2.21	45.98	1.78	66.66	6.97	197.22	12.81	130.37	16.89	75735	509.5	831.22	88.35	22816	453.5	15858	438.49	1857	234.8	4837
09-Nov	0.75	1.75	96.40	2.59	55.44	1.84	27.50	1.25	135.43	7.83	154.00	10.29	127.64	14.20	42431	312.5	387.43	68.79	15195	318.5	8577	278.65	1503	168.7	703
09-Nov	0.75	2.25	92.78	2.75	75.63	2.26	34.13	1.46	254.22	10.83	252.10	13.12	193.22	16.85	59914	407.2	961.14	84.38	20929	384.5	8618	299.05	2115	185.9	646
09-Nov	0.75	2.75	93.83	2.71	72.92	2.18	35.18	1.46	286.43	11.25	205.65	11.95	207.32	16.79	49628	359.5	1010.01	84.17	27651	416.4	8033	281.02	1609	172.8	644
09-Nov	1.25	0.25	156.14	3.47	67.27	2.18	44.80	1.68	107.35	7.84	144.09	10.85	141.77	16.05	51916	382.1	336.36	74.48	10729	307.1	13855	366.56	1416	203.5	1262
09-Nov	1.25	0.75	153.71	3.29	55.73	1.92	40.96	1.55	93.98	7.19	130.48	10.09	108.08	14.48	46780	345.2	489.10	74.51	10575	291.9	11605	330.73	1157	191.3	684
09-Nov	1.25	1.25	81.81	2.55	60.11	2.00	36.63	1.48	73.35	6.61	96.43	9.20	105.89	14.61	42526	330.5	384.51	72.94	15726	333.1	11538	324.80	1232	203.2	494
09-Nov	1.25	1.75	84.03	2.43	50.10	1.75	27.77	1.25	125.58	7.54	119.74	9.28	120.23	13.95	43459	315.1	216.81	64.89	13385	291.4	7560	254.22	1164	159.0	556
09-Nov	1.25	2.25	83.18	2.55	64.74	2.04	28.19	1.31	293.99	11.22	181.82	11.20	191.89	16.18	52747	366.3	725.49	77.91	18452	351.0	7525	270.64	2032	173.4	921
09-Nov	1.25	2.75	99.55	2.81	69.25	2.16	27.27	1.32	291.27	11.46	170.34	11.29	240.75	17.75	57729	396.9	966.46	84.53	24286	395.1	7279	269.90	1915	172.5	756
09-Nov	1.75	0.25	142.35	3.23	64.42	2.07	43.60	1.61	135.85	8.32	147.24	10.65	151.78	15.80	48763	357.5	325.68	72.13	11342	303.3	12285	341.26	1507	196.9	551
09-Nov	1.75	0.75	101.31	2.94	90.50	2.51	27.35	1.36	273.20	11.43	141.69	10.88	271.67	18.97	79655	492.8	395.66	75.44	13231	339.2	6926	287.35	2302	174.5	1548
09-Nov	1.75	1.25	109.40	3.14	107.26	2.80	32.97	1.51	203.85	10.35	130.02	10.81	263.88	19.27	81016	511.6	183.97	73.46	14529	351.4	7345	295.48	2313	179.7	1755
09-Nov	1.75	1.75	85.37	2.63	89.01	2.38	25.17	1.25	261.08	10.68	119.31	9.71	193.87	16.34	63864	410.2	367.08	71.26	11739	300.9	7031	268.81	1562	159.1	2053
09-Nov	1.75	2.25	82.19	2.48	68.98	2.05	26.44	1.24	272.79	10.56	149.37	10.17	181.39	15.54	55011	365.3	603.39	73.54	17085	335.0	6004	241.90	1915	161.4	1181
09-Nov	1.75	2.75	90.60	2.70	78.33	2.26	35.76	1.47	285.00	11.21	177.15	11.27	223.06	17.14	57781	389.5	846.04	80.74	27437	417.3	8051	283.57	1892	184.3	905
09-Nov	2.25	0.25	91.70	2.80	88.32	2.46	25.34	1.30	215.92	10.16	166.63	11.33	234.18	17.78	66243	431.6	762.49	80.98	17224	366.4	7162	284.61	2189	179.8	1201
09-Nov	2.25	0.75	113.39	3.01	108.98	2.67	27.11	1.32	204.27	9.79	174.08	11.30	206.27	16.91	56001	386.7	549.73	76.14	15923	334.0	7231	268.20	2289	185.0	975
09-Nov	2.25	1.25	127.36	3.18	100.89	2.60	34.78	1.48	230.66	10.45	101.62	9.57	186.76	16.83	62637	418.8	< LOD	134.20	9368	295.4	9056	312.89	1532	180.7	1066
09-Nov	2.25	1.75	103.36	2.72	74.02	2.12	31.72	1.35	225.81	9.79	153.16	10.34	202.85	16.13	54841	366.9	544.06	72.94	15228	340.0	8744	302.25	2015	186.0	983
09-Nov	2.25	2.25	101.52	2.92	96.87	2.57	26.56	1.34	285.28	11.54	168.53	11.36	206.88	17.27	67559	442.5	847.54	83.14	16263	359.2	7605	293.22	2129	176.9	1184
09-Nov	2.25	2.75	73.57	2.44	79.37	2.22	24.20	1.21	228.90	9.93	179.93	11.10	187.40	15.91	55365	370.9	887.80	79.51	28198	423.3	6499	259.03	1993	181.7	927
09-Nov	2.75	0.25	164.61	3.78	130.64	3.11	26.75	1.39	157.56	9.31	164.63	11.73	174.82	17.26	63169	438.7	901.90	87.25	19612	374.7	7054	272.52	2237	183.5	835
09-Nov	2.75	0.75	96.02	2.75	80.26	2.28	27.00	1.30	239.84	10.38	114.31	9.77	240.85	17.54	63605	412.7	527.41	74.88	12116	316.3	7150	280.60	2423	177.0	2114
09-Nov	2.75	1.25	92.92	2.52	123.78	2.55	24.72	1.14	228.69	9.19	143.06	9.45	220.28	15.56	68045	396.8	466.29	67.13	43824	539.0	6890	285.94	1824	191.4	827
09-Nov	2.75	1.75	101.89	2.74	75.24	2.16	24.30	1.21	203.20	9.43	162.70	10.66	175.67	15.63	55664	371.0	714.81	76.33	17817	355.4	7182	272.05	2018	174.1	1024
09-Nov	2.75	2.25	102.53	2.85	90.93	2.43	23.27	1.23	214.65	9.93	136.34	10.27	203.82	16.73	64843	420.2	985.80	83.45	17618	350.9	6587	262.65	1543	172.5	1264
09-Nov	2.75	2.75	86.69	2.56	69.62	2.08	22.04	1.17	192.75	9.22	143.48	10.14	176.32	15.60	47864	342.3	405.65	70.72	20526	348.4	6129	235.00	1420	158.3	886
16-Nov	0.25	0.25	115.47	3.14	71.24	2.30	40.47	1.65	301.19	12.24	149.32	11.28	226.14	18.35	70858	470.8	337.46	76.37	12204	325.4	9651	323.86	1885	174.0	1068
16-Nov	0.25	0.75																							941
16-Nov	0.25	1.25	87.74	2.64	67.17	2.10	31.21	1.39	495.38	14.48	185.77	11.42	186.75	16.18	53701	370.3	857.37	80.70	17686	343.1	7699	272.49	2193	175.0	737
16-Nov	0.25	1.75	102.45	2.81	70.88	2.16	35.71	1.47	387.68	12.92	178.32	11.32	166.72	15.93	55178	381.9	1014.96	84.11	20620	381.2	8377	297.31	2183	177.5	623
16-Nov	0.25	2.25	79.81	2.49	66.71	2.05	28.42	1.30	273.80	10.79	175.20	10.99	203.58	16.26	51045	357.1	902.56	80.42	21948	378.1	7809	278.29	2893	181.5	743
16-Nov	0.25	2.75	86.07	2.63	83.27	2.31	27.49	1.31	347.69	12.23	235.87	12.46	132.66	15.02	44006	337.6	1451.62	92.02	53944	556.0	8106	279.64	1647	202.3	490
16-Nov	0.75	0.25	83.22	2.90	97.07	2.74	37.69	1.64	183.71	10.14	134.40	11.29	199.84	18.58	93175	581.7	277.13	78.14	21433	431.9	12848	394.32	2081	210.1	2872
16-Nov	0.75	0.75	108.96	3.43	201.28	4.05	42.44	1.76	84.46	7.69	93.02	10.17	250.60	20.04	88768	576.7	205.39	78.36	32842	532.4	16159	447.79	2381	233.1	7574
16-Nov	0.75	1.25	161.78	3.68	130.72	3.06	51.12	1.82	77.05	7.15	153.36	11.35	122.22	16.12	48239	374.9	170.84	72.42	26476	429.8	15653	389.51	1357	219.0	2069
16-Nov	0.75	1.75	89.02	2.70	72.39	2.21	30.52	1.39	340.90	12.33	163.32	11.16	337.09	19.82	60913	409.5	406.50	73.57	17547	361.3	7433	286.63	2135	179.0	956
16-Nov	0.75	2.25	84.26	2.49	63.03	1.97	29.90	1.31	273.70	10.62	293.46	13.27	175.90	15.47	48855	342.9	847.83	78.15	24284	387.7	8066	276.33	2029	174.7	692
16-Nov	0.75	2.75	94.67	2.76	78.88	2.29	32.73	1.43	305.71	11.69	200.49	11.95	212.29	17.05	50846	368.5	1135.28	87.32	31801	450.0	8070	287.24	1900	185.4	647
16-Nov	1.25	0.25	83.74	2.64	82.18	2.33	31.81	1.40	212.79	9.96	111.53	9.73	230.30	17.39	58635	397.6	288.07	71.02	14716	334.7	8179	294.49	1809	168.3	1062
16-Nov	1.25	0.75	91.72	2.69	80.46	2.27	33.99	1.42	234.28	10.16	173.96	11.00	188.15	16.14	66373	417.0	589.92	74.72	18413	372.4	8086	298.65	1935	175.8	2124

Table A.2 Experiment III - Ferrous Smithing pXRF and magnetic susceptibility data 3 of 3

Date	Easting	Northing	Zr	Zr Error	Sr	Sr Error	Rb	Rb Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Ca	Ca Error	K	K Error	P	P Error	MagSus
16-Nov	1.25	1.25	93.39	2.83	93.78	2.54	29.43	1.39	222.86	10.37	121.13	10.20	210.32	17.41	64795	431.9	306.11	73.14	14634	341.8	7388	287.85	1872	170.5	1010
16-Nov	1.25	1.75	76.42	2.47	63.87	2.03	26.90	1.28	240.59	10.26	151.43	10.40	168.92	15.52	57745	382.3	533.88	73.73	16418	343.4	6972	271.06	1869	161.5	894
16-Nov	1.25	2.25	73.25	2.40	77.95	2.18	23.00	1.18	261.69	10.43	126.27	9.58	149.85	14.80	47103	335.0	678.79	75.42	16397	322.8	6587	246.67	1757	154.1	891
16-Nov	1.25	2.75	111.00	3.05	82.71	2.42	39.99	1.61	336.54	12.64	213.22	12.67	185.81	17.16	56037	404.1	1148.69	90.38	33248	473.0	9201	313.37	2023	193.4	793
16-Nov	1.75	0.25	114.68	3.11	96.46	2.61	34.41	1.51	223.72	10.55	100.68	9.82	198.67	17.27	65144	433.8	392.28	75.31	9238	287.7	8108	295.64	2139	179.0	1573
16-Nov	1.75	0.75	93.85	2.71	80.15	2.27	20.69	1.16	204.88	9.62	108.20	9.46	173.58	15.69	66719	422.4	218.43	68.61	13380	309.4	6081	253.04	1951	151.2	1748
16-Nov	1.75	1.25	103.06	2.83	95.44	2.46	18.68	1.12	167.98	8.87	115.88	9.63	165.49	15.60	64910	415.4	427.12	72.56	14716	335.6	5857	254.12	2245	164.5	1416
16-Nov	1.75	1.75	116.52	3.37	104.91	2.90	36.03	1.64	208.39	10.94	94.18	10.32	206.15	18.96	90249	575.3	< LOD	151.81	10779	338.4	8819	339.15	2043	185.2	1930
16-Nov	1.75	2.25	100.63	2.84	80.83	2.32	27.87	1.34	279.16	11.25	192.20	11.78	247.07	17.91	51749	374.9	829.45	82.15	36541	467.8	7497	271.18	1846	195.8	738
16-Nov	1.75	2.75	114.41	2.97	78.57	2.28	32.58	1.42	292.76	11.45	180.05	11.47	162.73	16.04	56214	390.5	997.58	84.66	28784	429.3	8006	285.14	1787	183.3	877
16-Nov	2.25	0.25	109.25	2.96	93.26	2.49	30.94	1.39	177.26	9.23	127.96	10.16	191.71	16.50	64223	417.3	350.92	72.00	12301	315.2	7327	278.53	2143	169.3	1638
16-Nov	2.25	0.75	83.12	2.63	82.90	2.33	26.42	1.30	224.88	10.19	150.44	10.72	177.62	16.14	65842	427.0	307.26	71.50	18601	369.1	5795	256.19	4945	196.8	1138
16-Nov	2.25	1.25	83.70	2.56	75.44	2.18	26.63	1.27	192.89	9.34	167.39	10.94	157.00	15.44	54946	375.0	363.82	70.78	21716	385.7	7835	284.82	2356	181.3	1168
16-Nov	2.25	1.75	114.07	3.12	89.32	2.53	33.69	1.51	213.85	10.45	130.45	10.61	151.23	16.31	66597	449.6	471.69	78.48	14674	338.9	8633	303.91	1648	175.8	1417
16-Nov	2.25	2.25	98.77	2.83	98.16	2.53	27.38	1.32	278.80	11.16	153.11	10.88	320.30	19.29	60550	405.0	557.38	76.23	17625	360.0	7866	290.55	1892	181.5	1268
16-Nov	2.25	2.75	84.65	2.61	105.47	2.55	25.97	1.26	305.78	11.30	221.78	12.01	193.82	16.05	52303	362.4	948.45	80.98	33279	445.6	6421	254.31	1698	175.3	1040
16-Nov	2.75	0.25	104.39	2.90	89.58	2.44	30.62	1.40	254.33	10.84	197.55	11.96	179.53	16.46	66623	432.9	875.08	82.47	17035	362.8	7497	289.61	2553	182.5	1519
16-Nov	2.75	0.75	101.75	2.97	84.71	2.46	30.56	1.44	249.08	11.10	129.58	10.68	220.93	18.04	79324	496.8	530.65	79.01	12461	330.9	7489	299.44	1764	167.2	1457
16-Nov	2.75	1.25	110.82	3.07	97.16	2.61	41.05	1.63	226.07	10.59	119.58	10.29	187.78	17.04	76410	482.5	333.66	74.80	11674	317.2	7030	286.11	1927	164.6	1994
16-Nov	2.75	1.75	106.41	3.14	88.16	2.60	28.94	1.46	271.93	11.97	149.85	11.64	203.01	18.37	86357	547.6	502.84	81.72	14262	361.2	7785	316.34	1864	187.9	1522
16-Nov	2.75	2.25	120.83	3.19	83.47	2.46	30.93	1.45	278.12	11.72	158.98	11.45	194.75	17.51	72315	473.8	500.35	78.99	18193	376.4	8257	303.92	1941	182.6	1336
16-Nov	2.75	2.75	104.51	2.95	87.21	2.45	26.90	1.34	196.88	9.85	112.63	9.99	157.38	16.28	64685	433.0	508.96	77.28	19679	382.2	7770	291.99	1144	172.9	1192

Figure A.5 Bubble plots of Zr, Pb, and Fe concentrations from Experiment IV Manor Farm, Sheffield alongside plans of the site with 0.3m (*left*) and 1m (*right*) diameter wells. *From left to right:* Day0, Day13, Day37, and Day43.

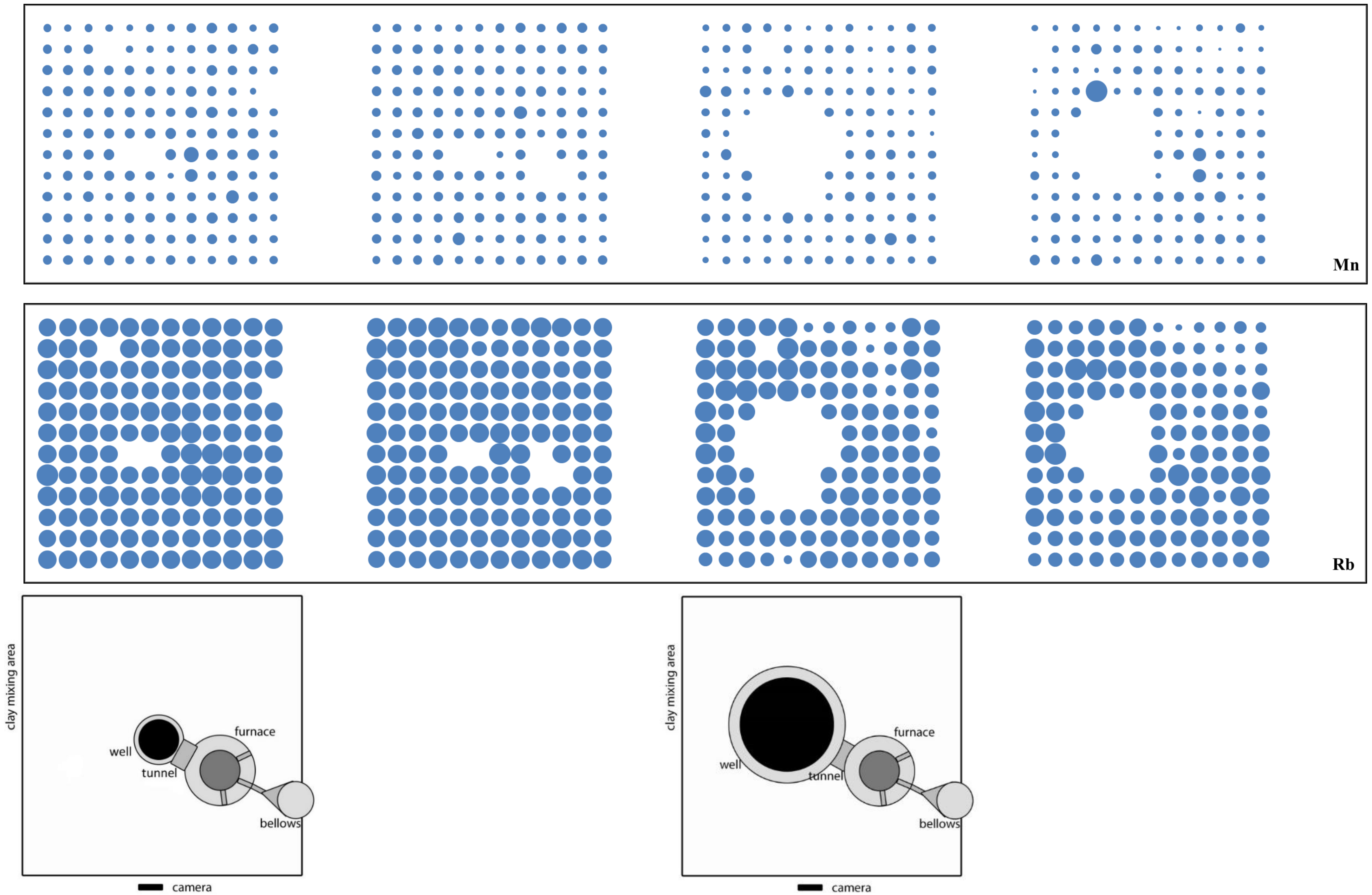


Figure A.6 Bubble plots of Mn and Rb concentrations from Experiment IV Manor Farm, Sheffield alongside plans of the site with 0.3m (*left*) and 1m (*right*) diameter wells. *From left to right:* Day0, Day13, Day37, and Day43.

Table A.3 Experiment IV - Copper Smelting pXRF and magnetic susceptibility data

Day	Easting	Northing	Zr	Zr Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Sr	Sr Error	Rb	Rb Error	Ca	Ca Error	K	K Error	MagSus
Day0	0.125	2.875	354.37	13.42	358.78	22.63	184.87	22.79	165.28	28.59	50205	584.4	537.49	100.33	< LOD	15.71	59.40	5.85	1891	224	9338	621.5	484
Day0	0.375	2.875	328.90	12.78	314.21	20.80	177.77	21.81	156.49	27.48	41885	522.8	437.08	91.52	< LOD	16.12	59.37	5.75	3670	294	10200	657.3	535
Day0	0.625	2.875	345.76	13.46	323.27	21.78	139.68	21.07	210.12	31.05	50655	593.0	554.33	103.61	< LOD	16.27	64.69	6.17	2091	236	10001	650.2	693
Day0	0.875	2.875	332.08	13.08	373.95	22.97	162.44	21.68	220.27	30.98	48323	571.0	493.57	96.84	< LOD	16.05	67.18	6.19	1848	227	10126	652.0	752
Day0	1.125	2.875	341.89	13.28	295.78	20.73	137.00	20.49	142.80	27.63	48388	574.5	393.53	92.77	< LOD	16.19	70.59	6.20	1530	215	10565	667.1	557
Day0	1.375	2.875	328.70	12.90	363.78	22.47	103.77	18.55	147.93	27.37	43693	538.5	558.69	98.25	< LOD	15.33	64.25	6.01	1586	215	10295	652.5	519
Day0	1.625	2.875	368.52	13.48	395.97	23.32	252.65	25.18	178.68	28.84	46507	555.2	505.64	96.71	< LOD	15.67	60.44	5.89	2475	254	9769	649.4	433
Day0	1.875	2.875	391.41	13.60	197.58	16.89	122.06	18.87	108.40	25.01	34862	476.5	737.98	104.60	< LOD	15.47	61.38	5.86	1911	232	10753	672.6	322
Day0	2.125	2.875	318.92	12.65	312.04	20.79	131.59	19.64	145.02	27.00	43332	533.3	936.01	116.38	< LOD	15.23	68.67	6.01	2382	247	10371	657.0	605
Day0	2.375	2.875	298.22	12.57	379.04	23.08	188.86	22.90	180.99	29.25	49668	579.7	737.12	110.33	< LOD	15.64	61.91	5.86	2443	249	9422	631.8	466
Day0	2.625	2.875	323.15	13.05	421.09	24.48	158.97	21.69	167.62	28.95	50065	586.4	501.56	99.02	< LOD	15.35	66.17	6.17	2068	233	9949	642.4	
Day0	2.875	2.875	340.49	13.06	375.19	22.68	246.83	24.85	172.47	28.50	44898	544.5	730.61	107.65	< LOD	16.40	63.60	5.92	3453	283	9742	637.7	496
Day0	0.125	2.625	301.10	12.57	352.48	22.30	213.17	23.78	197.16	29.88	48682	571.9	706.92	108.36	< LOD	16.48	71.80	6.33	2725	263	10720	672.8	518
Day0	0.375	2.625	307.56	12.66	408.96	23.86	207.74	23.58	179.78	29.20	49334	576.1	548.38	100.96	< LOD	15.74	68.11	6.15	2606	255	9979	646.5	578
Day0	0.625	2.625	335.04	12.96	415.76	23.87	249.61	24.90	170.17	28.43	44389	542.4	722.33	106.55	< LOD	15.45	61.06	5.84	3311	281	9824	645.0	413
Day0	0.875	2.625																					444
Day0	1.125	2.625	336.07	13.17	404.88	23.95	209.19	23.89	204.58	30.57	48181	573.4	431.67	95.01	< LOD	15.74	69.73	6.19	2095	237	10444	660.9	485
Day0	1.375	2.625	413.19	14.28	338.10	22.03	144.55	20.93	147.07	28.06	48099	572.7	422.55	94.25	< LOD	15.88	65.38	6.13	1781	223	10305	653.8	455
Day0	1.625	2.625	336.58	12.99	390.79	23.16	183.70	22.30	152.37	27.76	44996	545.5	489.04	94.89	< LOD	15.84	66.05	6.01	1901	230	10845	669.5	473
Day0	1.875	2.625	279.53	12.14	410.84	23.73	255.43	25.04	202.42	29.64	44689	543.4	620.63	101.57	< LOD	15.49	66.24	5.95	3027	269	9786	638.7	461
Day0	2.125	2.625	304.93	12.67	432.86	24.55	259.90	25.78	180.05	29.29	48588	571.8	685.41	107.51	< LOD	16.07	67.06	6.18	2929	268	9811	643.5	479
Day0	2.375	2.625	424.67	14.30	488.56	25.85	291.12	26.65	168.99	28.93	40744	522.4	697.55	105.63	< LOD	15.67	71.74	6.25	2591	256	10196	656.3	445
Day0	2.625	2.625	302.43	12.69	366.25	22.85	259.11	26.02	161.66	28.88	53429	604.4	917.09	120.42	< LOD	16.26	61.05	5.94	3407	282	9525	632.5	649
Day0	2.875	2.625	286.15	12.01	430.76	23.81	247.98	24.43	162.19	27.43	45680	540.1	691.76	104.03	< LOD	15.48	65.49	5.83	3818	300	9673	645.3	478
Day0	0.125	2.375	328.90	12.68	244.57	18.50	164.73	20.94	93.79	24.31	40439	511.9	803.30	108.70	< LOD	14.81	71.89	6.15	2081	238	11411	686.9	287
Day0	0.375	2.375	374.83	13.50	298.08	20.38	218.79	23.48	121.69	26.17	43580	535.5	827.89	111.06	< LOD	16.05	73.44	6.31	2839	267	11202	684.2	473
Day0	0.625	2.375	293.33	12.25	356.90	22.09	258.74	25.14	134.32	26.49	43111	531.2	886.39	114.17	< LOD	15.42	61.54	5.68	3206	278	10375	660.4	474
Day0	0.875	2.375	329.47	12.61	329.70	20.97	213.00	23.09	144.53	26.81	43388	526.0	736.77	105.26	< LOD	14.78	61.33	5.72	3265	278	10275	652.9	596
Day0	1.125	2.375	372.29	13.45	385.13	22.92	222.33	23.74	161.98	27.94	44155	538.9	730.73	106.53	< LOD	15.38	62.66	5.91	3460	287	10401	663.1	504
Day0	1.375	2.375	313.98	12.74	362.24	22.56	191.16	22.78	137.01	27.16	48530	570.7	606.96	102.88	< LOD	15.67	63.95	5.97	2346	243	9468	627.0	616
Day0	1.625	2.375	328.14	12.65	304.32	20.32	206.80	22.80	139.95	26.56	39229	502.6	631.71	99.56	< LOD	15.33	64.20	5.84	2943	269	10346	661.3	380
Day0	1.875	2.375	304.78	12.40	364.52	22.22	196.47	22.53	172.00	28.04	42816	527.5	550.65	96.90	< LOD	15.51	67.37	6.01	3037	273	10374	660.6	560
Day0	2.125	2.375	385.12	13.80	354.64	22.32	260.58	25.43	175.78	28.77	41241	526.9	908.28	115.48	< LOD	16.02	67.54	6.14	2761	261	10660	663.7	497
Day0	2.375	2.375	339.04	13.34	364.75	22.95	207.92	24.04	136.55	27.85	47744	576.2	746.40	111.57	< LOD	15.84	72.16	6.40	2866	266	10544	664.6	328
Day0	2.625	2.375	337.45	12.88	367.19	22.31	298.21	26.45	193.95	29.14	41870	521.8	611.01	100.72	< LOD	15.66	60.37	5.81	3284	277	9480	628.2	456
Day0	2.875	2.375	285.46	12.11	375.34	22.63	225.23	23.79	138.75	26.81	48169	561.0	584.06	101.21	< LOD	15.10	64.35	5.89	2999	266	9192	617.9	573
Day0	0.125	2.125	307.57	12.41	351.17	21.81	256.23	24.90	155.76	27.31	42461	525.4	819.16	109.71	< LOD	15.18	63.76	5.81	3097	273	9802	643.6	461
Day0	0.375	2.125	334.56	12.76	351.55	21.77	247.72	24.28	134.10	26.07	40498	509.6	889.18	112.10	< LOD	15.32	65.41	5.91	3254	278	10289	654.3	451
Day0	0.625	2.125	302.92	12.05	352.11	21.35	265.27	24.58	149.52	26.32	40153	498.8	833.52	106.97	< LOD	14.68	66.06	5.80	3464	286	10479	661.1	467
Day0	0.875	2.125	335.46	12.93	364.99	22.38	281.11	25.84	148.50	27.13	42179	526.4	931.61	115.75	< LOD	15.79	58.35	5.67	3695	291	10486	655.7	459
Day0	1.125	2.125	295.45	12.28	377.01	22.62	250.69	24.96	150.92	27.47	42203	527.0	923.90	115.52	< LOD	15.36	57.40	5.63	3729	291	9836	638.8	384
Day0	1.375	2.125	281.31	12.09	365.71	22.34	235.46	24.07	142.14	26.95	42470	527.9	871.19	112.87	< LOD	15.60	59.92	5.73	3382	282	10698	663.1	488

Table A.3 Experiment IV - Copper Smelting pXRF and magnetic susceptibility data

Day	Easting	Northing	Zr	Zr Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Sr	Sr Error	Rb	Rb Error	Ca	Ca Error	K	K Error	MagSus
Day0	1.625	2.125	334.30	12.76	373.59	22.35	264.41	25.06	148.63	27.02	42460	523.5	632.15	100.87	< LOD	15.43	60.55	5.74	3462	285	10686	664.4	409
Day0	1.875	2.125	328.46	12.73	348.37	21.77	195.52	22.43	143.27	26.88	42491	525.5	918.04	114.20	< LOD	15.34	63.76	5.92	2704	262	11473	690.0	683
Day0	2.125	2.125	346.83	13.18	293.01	20.43	207.33	23.21	117.92	26.20	42797	535.5	779.94	109.64	< LOD	15.22	64.00	5.91	2816	265	10873	674.7	390
Day0	2.375	2.125	363.94	14.07	547.49	28.43	235.47	26.27	270.38	35.05	62866	674.0	582.04	109.91	< LOD	16.65	68.81	6.40	2073	236	10349	659.7	1010
Day0	2.625	2.125	314.78	12.73	376.48	22.90	170.09	21.85	213.25	30.50	47893	565.3	354.87	89.12	< LOD	15.51	62.48	5.91	1854	223	9840	635.6	740
Day0	2.875	2.125																					539
Day0	0.125	1.875	290.79	12.39	372.57	22.77	256.85	25.40	176.49	28.88	44683	546.7	869.70	114.25	< LOD	16.07	68.88	6.09	3248	276	9759	637.3	471
Day0	0.375	1.875	281.51	12.06	366.33	22.31	266.18	25.20	167.33	27.89	42646	526.6	757.49	107.20	< LOD	15.57	67.13	5.98	3150	277	10964	676.7	361
Day0	0.625	1.875	314.21	12.50	311.87	20.68	248.61	24.45	143.07	26.71	39567	506.6	738.93	104.98	< LOD	15.40	61.37	5.79	3683	295	10769	672.8	372
Day0	0.875	1.875	296.20	12.33	355.80	22.08	252.96	24.90	128.23	26.38	42423	528.4	779.17	109.18	< LOD	15.76	67.01	6.05	3342	282	10851	671.4	361
Day0	1.125	1.875	319.91	12.77	372.16	22.72	223.09	24.10	142.29	27.30	50014	577.1	843.83	114.36	< LOD	15.27	67.61	6.11	2261	242	10045	647.9	460
Day0	1.375	1.875	355.84	13.24	300.83	20.52	172.92	21.77	137.06	26.91	43598	537.0	757.32	108.78	< LOD	15.59	71.41	6.14	2668	262	11161	686.0	340
Day0	1.625	1.875	384.44	13.60	238.86	18.46	169.95	21.52	138.08	26.88	39996	513.3	723.96	105.38	< LOD	15.63	73.53	6.26	2945	268	10754	667.0	318
Day0	1.875	1.875	332.87	13.02	280.92	20.15	132.51	20.14	161.91	28.41	48307	571.0	1086.39	124.76	< LOD	15.06	68.98	6.10	1742	224	10606	666.6	482
Day0	2.125	1.875	367.30	13.07	265.11	18.87	181.79	21.32	92.16	23.86	36784	481.5	1064.88	116.97	< LOD	15.38	62.48	5.67	2927	273	11348	694.7	288
Day0	2.375	1.875	314.99	12.55	371.08	22.44	270.60	25.49	151.88	27.20	41966	522.9	693.24	104.24	< LOD	15.43	60.89	5.78	3990	305	10569	668.3	492
Day0	2.625	1.875	303.73	12.53	395.54	23.31	252.70	25.19	154.50	27.75	43651	538.4	753.65	108.90	< LOD	16.09	63.45	5.87	3866	297	10038	646.6	421
Day0	2.875	1.875	341.32	13.23	411.05	24.01	252.32	25.68	216.04	31.09	54323	605.9	551.43	102.66	< LOD	15.87	65.59	6.13	2474	249	9620	633.9	720
Day0	0.125	1.625	340.89	13.01	343.18	21.77	235.91	24.36	140.16	26.99	44446	541.9	723.60	106.82	< LOD	15.47	68.08	6.04	3455	287	10618	669.1	391
Day0	0.375	1.625	327.41	12.84	354.85	22.15	247.56	24.86	164.91	28.23	43078	534.7	730.56	106.69	< LOD	15.57	65.27	5.95	3180	278	10579	667.2	382
Day0	0.625	1.625	333.06	12.95	369.93	22.57	257.94	25.28	174.90	28.68	44626	543.5	780.03	109.63	< LOD	15.98	67.10	6.05	3219	277	10325	655.6	560
Day0	0.875	1.625	271.56	11.72	324.83	20.81	264.76	24.94	126.80	25.78	39585	502.7	865.95	110.43	< LOD	15.08	61.04	5.72	3851	298	10233	656.0	369
Day0	1.125	1.625	313.38	12.38	277.81	19.47	228.59	23.47	121.61	25.56	39009	500.0	874.13	110.55	< LOD	14.79	60.45	5.66	3366	289	11798	708.4	327
Day0	1.375	1.625	328.92	12.81	305.25	20.62	205.49	22.87	144.65	27.01	39826	512.3	903.32	113.70	< LOD	15.34	63.13	5.93	2879	267	10807	671.6	420
Day0	1.625	1.625	294.61	12.46	366.16	22.65	194.41	23.03	118.65	26.31	48860	572.7	955.44	119.82	< LOD	16.13	75.69	6.44	2414	252	11594	694.3	338
Day0	1.875	1.625	313.26	12.87	356.37	22.67	118.98	19.75	186.66	29.91	50858	591.4	691.36	108.73	< LOD	15.46	80.40	6.63	1379	204	9863	638.7	643
Day0	2.125	1.625	311.61	12.41	327.60	21.06	238.66	23.94	152.12	27.03	39034	501.3	825.62	109.01	< LOD	15.24	59.40	5.64	3659	291	10056	648.5	381
Day0	2.375	1.625	297.96	12.46	344.89	21.99	288.00	26.51	169.35	28.56	44988	548.3	893.05	115.41	< LOD	15.93	64.41	5.97	4451	315	10673	663.8	403
Day0	2.625	1.625	314.46	12.62	377.17	22.76	245.17	24.80	171.03	28.32	47402	558.9	878.74	114.37	< LOD	15.40	57.69	5.67	3242	278	9818	642.4	626
Day0	2.875	1.625	289.53	12.34	391.85	23.36	198.52	23.17	173.94	28.68	48071	567.2	540.61	99.87	< LOD	15.44	61.59	5.91	2456	250	9892	645.0	555
Day0	0.125	1.375	323.38	12.63	324.44	20.99	222.22	23.58	164.82	27.82	40769	514.4	729.22	105.69	< LOD	15.43	67.24	6.01	3513	289	10832	673.7	355
Day0	0.375	1.375	308.95	12.31	299.28	20.07	243.00	24.00	146.91	26.75	39726	502.9	760.88	105.69	< LOD	15.14	66.11	5.88	3075	277	11684	699.0	312
Day0	0.625	1.375	280.42	12.06	318.13	20.98	270.01	25.44	124.20	25.88	38954	505.3	793.31	108.32	< LOD	15.31	64.04	5.91	3873	296	10544	658.3	318
Day0	0.875	1.375	300.94	12.20	348.93	21.58	265.19	24.90	131.71	26.03	41065	512.9	934.31	113.16	< LOD	15.05	61.52	5.72	3623	290	10063	650.2	514
Day0	1.125	1.375																					
Day0	1.375	1.375																					
Day0	1.625	1.375	349.30	13.30	346.83	22.13	232.36	24.69	159.70	28.46	49099	575.3	943.38	119.45	< LOD	16.01	67.27	6.18	3058	269	10151	646.2	357
Day0	1.875	1.375	404.35	14.72	55.27	11.07	71.67	18.26	< LOD	34.29	63117	683.9	1884.33	163.97	< LOD	16.05	83.72	7.00	942	190	11933	700.6	424
Day0	2.125	1.375	542.62	15.29	23.72	8.14	48.08	13.56	31.23	20.35	21198	368.5	1083.35	114.85	< LOD	15.21	81.96	6.35	1049	205	14338	766.2	341
Day0	2.375	1.375	506.58	14.78	32.61	8.80	52.73	14.01	< LOD	29.98	22309	375.8	869.69	105.53	< LOD	14.33	70.14	5.96	686	189	14221	766.7	450
Day0	2.625	1.375	329.92	13.05	369.68	22.87	295.19	26.87	153.62	27.94	44322	547.6	1030.51	122.35	< LOD	16.07	66.28	6.04	3596	290	10549	663.6	487
Day0	2.875	1.375	273.91	12.04	427.57	24.24	210.90	23.39	134.54	26.79	44490	544.4	605.50	101.59	< LOD	15.13	60.06	5.85	4051	304	9695	639.9	440

Table A.3 Experiment IV - Copper Smelting pXRF and magnetic susceptibility data

Day	Easting	Northing	Zr	Zr Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Sr	Sr Error	Rb	Rb Error	Ca	Ca Error	K	K Error	MagSus
Day0	0.125	1.125	380.60	13.47	131.25	14.25	104.30	17.88	90.41	24.33	35908	483.4	492.18	91.43	< LOD	15.55	88.44	6.68	2037	245	14593	771.3	139
Day0	0.375	1.125	319.44	12.57	348.62	21.70	231.08	23.89	140.60	26.65	38921	503.1	767.45	106.73	< LOD	15.16	61.74	5.76	3837	298	10786	671.9	371
Day0	0.625	1.125	344.40	13.01	347.08	21.79	219.18	23.53	154.31	27.37	42162	525.4	761.19	107.80	< LOD	15.35	57.70	5.73	3463	285	10181	652.1	358
Day0	0.875	1.125	305.60	12.41	313.66	20.78	192.79	22.30	141.18	26.82	41880	523.3	799.19	109.16	< LOD	15.43	62.91	5.90	3306	280	10419	658.9	462
Day0	1.125	1.125	342.79	13.14	360.13	22.43	223.99	23.95	142.07	27.16	42809	535.1	818.12	111.58	< LOD	15.90	60.38	5.83	3733	290	10113	642.6	429
Day0	1.375	1.125	302.91	12.35	371.48	22.44	193.20	22.50	138.47	26.70	44302	537.4	698.30	104.95	< LOD	15.05	58.89	5.71	3152	278	10408	665.8	372
Day0	1.625	1.125	295.72	12.26	319.77	20.92	117.71	19.01	174.16	28.26	44463	536.8	313.52	84.32	< LOD	15.23	63.53	5.91	1332	203	10270	653.6	419
Day0	1.875	1.125	552.52	15.38	36.08	8.97	58.40	14.32	48.46	21.33	22102	375.3	1337.08	124.76	< LOD	15.03	83.50	6.42	951	204	14525	779.6	741
Day0	2.125	1.125	469.07	14.37	50.70	9.88	53.32	14.05	42.41	20.86	24073	391.0	624.35	93.55	< LOD	14.72	75.88	6.15	805	198	14844	789.0	398
Day0	2.375	1.125	504.53	14.88	32.77	8.76	38.14	13.22	< LOD	29.00	24609	397.3	876.67	107.14	< LOD	15.14	77.59	6.37	811	190	13184	736.4	361
Day0	2.625	1.125	322.00	12.80	391.71	23.22	223.65	24.11	158.41	27.98	44301	543.6	599.20	101.46	< LOD	15.60	61.42	5.98	3360	281	9892	643.9	446
Day0	2.875	1.125	320.27	12.81	435.40	24.44	231.61	24.44	179.02	28.84	46472	556.0	547.44	99.50	< LOD	15.78	65.60	6.04	2957	269	9889	647.7	622
Day0	0.125	0.875	344.60	13.04	283.83	19.93	193.69	22.43	116.35	25.70	39490	509.8	763.75	107.44	< LOD	15.80	72.43	6.29	3035	275	11743	700.7	306
Day0	0.375	0.875	334.94	13.01	405.68	23.65	210.21	23.41	188.60	29.20	45786	552.6	586.49	101.11	< LOD	15.60	62.87	5.98	2916	264	9768	635.1	436
Day0	0.625	0.875	337.93	13.10	504.24	26.24	236.39	24.62	136.51	27.14	48017	567.4	890.88	116.30	< LOD	15.88	62.75	5.89	3134	275	9821	643.5	454
Day0	0.875	0.875	394.68	13.73	206.11	17.23	118.05	18.85	100.43	24.95	38833	504.7	528.16	95.08	< LOD	16.21	78.60	6.37	2990	277	13667	749.9	304
Day0	1.125	0.875	365.67	13.36	370.08	22.54	253.20	24.95	170.10	28.30	44541	541.9	834.56	111.54	< LOD	15.52	62.35	5.83	3655	294	11015	678.1	379
Day0	1.375	0.875	312.70	12.67	384.29	23.06	183.80	22.49	234.95	31.32	45852	552.0	619.84	103.04	< LOD	15.77	67.13	6.07	2538	253	10469	660.4	567
Day0	1.625	0.875	331.11	13.07	348.54	22.30	161.33	21.70	133.51	27.27	53495	603.5	627.24	106.52	< LOD	15.52	67.28	6.16	2388	248	10117	653.0	667
Day0	1.875	0.875	488.07	14.65	24.59	8.18	37.80	13.15	< LOD	29.30	24201	393.3	654.37	95.94	< LOD	14.94	78.10	6.33	1102	207	14115	762.0	488
Day0	2.125	0.875	455.30	14.21	45.42	9.68	54.34	14.03	< LOD	30.11	23503	386.5	578.68	91.60	< LOD	15.06	80.68	6.36	1028	208	15018	788.7	625
Day0	2.375	0.875	473.47	15.25	57.89	10.96	40.59	14.94	38.61	22.82	47016	573.9	1391.22	139.35	< LOD	15.85	65.89	6.22	908	186	11461	686.7	414
Day0	2.625	0.875	314.94	12.81	374.03	22.97	222.52	24.22	164.09	28.47	45315	554.1	720.07	108.11	< LOD	15.49	58.32	5.85	4071	302	10529	657.5	510
Day0	2.875	0.875	328.39	12.86	431.70	24.23	270.16	25.61	166.85	28.17	42597	530.5	653.86	103.43	< LOD	15.67	64.22	5.99	3791	294	10398	654.6	483
Day0	0.125	0.625	318.29	12.52	368.69	22.21	236.50	24.06	157.39	27.43	42657	525.2	754.44	106.93	< LOD	15.37	61.01	5.69	3747	292	10122	646.8	440
Day0	0.375	0.625	284.96	12.28	366.81	22.64	237.42	25.00	192.51	29.67	51908	590.7	706.39	109.39	< LOD	15.42	65.23	6.01	3234	277	9578	635.8	407
Day0	0.625	0.625	339.38	13.19	351.53	22.36	177.41	22.44	244.80	32.08	47444	567.4	605.20	103.06	< LOD	15.44	64.72	6.06	2454	248	9563	631.3	480
Day0	0.875	0.625	335.09	13.13	348.45	22.26	158.84	21.43	143.38	27.54	47842	569.4	593.26	103.07	< LOD	15.73	57.52	5.83	2384	246	10097	646.7	454
Day0	1.125	0.625	293.94	12.33	365.50	22.44	212.73	23.38	152.92	27.51	44845	544.5	787.69	109.38	< LOD	15.85	64.26	6.04	3275	279	10368	657.5	437
Day0	1.375	0.625	326.72	12.79	367.90	22.44	216.56	23.49	172.00	28.23	45111	544.3	772.79	109.54	< LOD	15.30	58.60	5.76	3635	290	10410	657.3	579
Day0	1.625	0.625	295.61	12.54	352.42	22.38	216.02	24.21	180.45	29.54	48980	578.3	770.26	112.27	< LOD	15.60	66.56	6.06	3679	292	10536	662.0	436
Day0	1.875	0.625	330.68	12.85	387.93	23.03	333.95	28.08	241.13	31.33	42761	531.6	822.39	111.19	< LOD	15.42	58.28	5.73	4279	312	9923	649.6	462
Day0	2.125	0.625	323.72	12.99	390.66	23.48	258.51	25.72	166.00	28.71	47892	571.5	1001.63	121.99	< LOD	15.94	63.86	6.01	4557	319	10231	653.6	401
Day0	2.375	0.625	341.67	13.11	366.65	22.57	281.35	26.17	157.76	27.93	43210	536.4	833.04	112.02	< LOD	15.69	66.07	5.97	4445	313	9905	641.3	373
Day0	2.625	0.625	286.14	12.19	364.61	22.37	219.66	23.63	154.96	27.56	47097	556.6	602.31	101.15	< LOD	15.44	63.02	5.97	4088	308	10714	672.8	536
Day0	2.875	0.625	338.52	13.15	383.64	23.20	141.67	20.84	204.74	30.47	51178	587.5	460.96	96.85	< LOD	15.88	70.12	6.23	1937	233	10655	671.6	675
Day0	0.125	0.375	320.24	12.61	392.40	22.95	217.14	23.37	144.96	26.93	44771	538.8	728.38	106.19	< LOD	15.35	56.75	5.67	3852	295	9180	619.7	615
Day0	0.375	0.375	314.81	12.62	373.08	22.60	239.80	24.49	171.32	28.40	45802	548.6	824.87	111.53	< LOD	15.57	60.49	5.76	3663	290	9637	634.5	536
Day0	0.625	0.375	304.92	12.41	350.84	21.86	252.41	24.85	168.85	27.99	43056	530.0	668.16	103.09	< LOD	15.34	57.42	5.70	3519	287	10204	653.3	567
Day0	0.875	0.375	375.96	13.69	354.76	22.28	200.80	23.25	158.59	28.24	49111	573.4	634.67	104.78	< LOD	17.21	66.97	6.14	3519	290	10381	664.3	467
Day0	1.125	0.375	272.09	11.79	369.26	22.19	186.09	21.77	143.32	26.51	41283	514.6	751.33	105.43	< LOD	15.24	63.41	5.74	4113	309	10424	665.8	397
Day0	1.375	0.375	309.30	12.66	356.35	22.31	204.71	23.35	164.40	28.38	46766	560.7	783.28	111.92	< LOD	15.37	58.68	5.78	3321	281	10747	667.4	380

Table A.3 Experiment IV - Copper Smelting pXRF and magnetic susceptibility data

Day	Easting	Northing	Zr	Zr Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Sr	Sr Error	Rb	Rb Error	Ca	Ca Error	K	K Error	MagSus
Day0	1.625	0.375	253.92	11.32	313.45	20.27	240.10	23.54	123.25	25.16	38809	491.4	675.20	99.99	< LOD	14.96	55.99	5.45	3956	299	9921	643.0	366
Day0	1.875	0.375	275.58	11.72	303.53	20.08	188.36	21.69	148.06	26.37	37828	488.0	719.79	102.30	< LOD	15.24	62.83	5.77	4205	311	10300	663.2	354
Day0	2.125	0.375	312.79	12.53	326.66	21.20	256.61	24.82	144.73	26.88	40331	513.1	828.22	110.14	< LOD	15.58	62.11	5.84	4655	323	10373	660.0	376
Day0	2.375	0.375	300.74	12.26	355.95	21.87	223.31	23.51	160.28	27.61	42038	520.3	604.90	98.63	< LOD	15.19	64.89	5.93	4173	310	10698	670.5	423
Day0	2.625	0.375	336.72	13.02	356.52	22.28	208.45	23.13	156.67	27.76	42144	528.9	647.21	102.62	< LOD	15.72	67.57	6.13	4162	310	11209	684.6	453
Day0	2.875	0.375	308.66	12.66	445.59	24.71	201.15	23.11	247.51	31.86	45824	552.7	541.05	98.64	< LOD	16.38	73.75	6.27	2875	265	10806	668.0	658
Day0	0.125	0.125	363.06	13.67	434.11	24.92	209.06	23.80	146.75	28.06	48260	577.4	719.84	110.56	< LOD	15.90	66.28	6.18	3714	293	9865	644.2	445
Day0	0.375	0.125	317.11	12.75	346.14	21.97	191.08	22.77	170.08	28.64	47392	562.0	779.93	110.35	< LOD	16.39	64.50	6.02	3834	297	9686	639.8	417
Day0	0.625	0.125	298.61	12.31	365.49	22.25	238.03	24.13	149.40	26.99	40168	511.7	754.99	106.24	< LOD	15.91	62.40	5.83	4692	321	9920	642.9	393
Day0	0.875	0.125	293.20	12.53	442.26	24.99	303.88	27.62	157.84	28.46	55685	616.7	814.75	116.10	< LOD	15.76	60.43	5.96	2609	252	9282	621.2	1297
Day0	1.125	0.125	344.51	13.20	505.91	26.27	184.54	22.57	145.19	27.43	46392	557.0	637.63	103.46	< LOD	16.05	66.73	6.06	3081	276	10914	679.3	440
Day0	1.375	0.125	280.49	12.14	354.12	22.20	146.80	20.83	157.11	27.96	50716	580.1	634.47	104.69	< LOD	15.21	63.35	5.96	2601	255	9813	641.6	508
Day0	1.625	0.125	356.44	13.30	350.14	22.07	184.23	22.36	176.95	28.77	46300	554.9	700.69	106.27	< LOD	15.69	66.59	6.04	3301	282	10772	672.0	472
Day0	1.875	0.125	373.23	13.50	371.45	22.61	211.33	23.42	132.13	26.67	45149	546.3	631.19	103.44	< LOD	15.63	68.35	6.15	3944	301	11105	677.7	443
Day0	2.125	0.125	287.79	12.25	581.82	27.89	193.74	22.68	161.44	27.93	46151	552.0	592.16	100.28	< LOD	15.29	67.71	6.01	2724	263	10545	668.9	437
Day0	2.375	0.125	306.67	12.99	771.59	32.94	195.14	23.67	142.17	28.37	52974	609.7	783.26	116.04	< LOD	16.70	71.92	6.45	3273	278	10003	645.5	408
Day0	2.625	0.125	313.46	12.82	382.46	23.24	201.94	23.22	156.20	28.14	44333	548.1	582.80	101.79	< LOD	16.28	71.67	6.30	3603	290	10785	669.1	414
Day0	2.875	0.125	342.20	13.12	381.22	22.98	196.87	22.88	159.86	28.09	43952	541.8	639.64	103.41	< LOD	15.83	70.46	6.13	3221	278	10373	660.0	427
Day13	0.125	2.875	305.43	12.56	343.58	21.87	147.60	20.89	188.31	29.38	48367	566.7	572.00	101.04	< LOD	16.06	67.29	6.13	2678	260	10895	672.5	650
Day13	0.375	2.875	395.66	14.16	364.64	22.93	195.07	23.40	185.26	30.08	47110	570.8	636.19	106.16	< LOD	16.59	71.12	6.33	2701	258	10499	657.5	632
Day13	0.625	2.875	328.37	13.02	383.94	23.24	147.16	20.84	181.55	29.38	47049	563.8	449.78	94.87	< LOD	16.18	67.67	6.17	2132	238	10616	663.1	606
Day13	0.875	2.875	323.30	13.03	399.58	23.81	121.93	19.78	223.99	31.27	45351	555.6	442.82	94.89	< LOD	17.00	74.58	6.40	2858	267	11020	678.2	539
Day13	1.125	2.875	318.69	12.92	397.22	23.72	111.71	19.35	273.17	33.30	45499	557.8	457.46	95.59	< LOD	15.71	72.27	6.28	2053	236	10887	672.2	595
Day13	1.375	2.875	300.95	12.67	473.31	25.64	159.47	21.41	207.88	30.52	42829	538.8	529.15	98.22	< LOD	17.26	65.47	6.17	4322	315	11420	690.2	409
Day13	1.625	2.875	360.70	13.53	337.83	21.85	215.63	23.71	170.74	28.90	45558	553.1	695.32	107.47	< LOD	17.97	54.61	5.68	7152	393	11493	698.5	467
Day13	1.875	2.875	364.85	13.77	304.31	20.96	255.93	25.76	183.49	29.73	43558	545.8	826.16	113.61	25.12	13.15	66.37	6.21	15433	565	13958	777.2	477
Day13	2.125	2.875	295.31	12.67	164.94	15.96	306.03	27.11	119.96	26.66	41127	526.1	615.38	101.69	45.16	13.54	79.73	6.55	18879	617	17218	850.6	1941
Day13	2.375	2.875	361.49	13.44	277.45	19.83	229.12	24.25	155.25	27.98	39294	512.2	894.36	114.29	< LOD	17.75	72.10	6.19	8784	432	14748	783.0	963
Day13	2.625	2.875	312.11	12.86	320.32	21.17	206.30	23.17	164.71	28.48	38996	509.2	828.52	110.71	61.32	13.80	58.80	5.81	17048	580	13749	759.7	344
Day13	2.875	2.875	316.99	12.97	379.76	23.23	259.34	25.80	210.67	30.79	45733	558.3	638.97	105.02	< LOD	17.45	67.60	6.20	6205	367	10810	675.8	428
Day13	0.125	2.625	340.76	13.32	372.81	23.10	192.73	23.09	144.66	27.99	45568	558.5	722.63	109.57	< LOD	16.97	79.51	6.57	3615	291	10954	674.2	584
Day13	0.375	2.625	311.02	12.78	402.74	23.70	209.17	23.65	165.28	28.65	43039	539.8	732.21	108.30	< LOD	16.92	72.05	6.26	4240	314	11673	700.3	433
Day13	0.625	2.625	361.17	13.54	348.79	22.25	205.64	23.64	116.97	26.57	46217	560.4	787.14	112.44	< LOD	16.70	62.90	5.96	4161	307	11205	679.4	485
Day13	0.875	2.625	308.86	12.90	362.83	22.84	230.16	24.87	217.69	31.38	48867	579.8	735.75	111.13	< LOD	17.65	71.16	6.35	4722	325	10640	667.1	405
Day13	1.125	2.625	644.53	17.57	364.77	23.19	221.81	24.90	170.86	29.91	46461	573.0	696.64	110.92	< LOD	18.50	68.83	6.38	5134	335	10396	659.0	403
Day13	1.375	2.625	220.55	11.20	142.25	14.58	111.50	17.85	88.44	24.07	32147	456.1	662.11	98.97	52.79	13.48	43.63	5.12	20855	635	11804	710.5	200
Day13	1.625	2.625	309.28	12.90	327.32	21.48	164.02	21.50	155.93	28.13	39859	518.2	620.30	101.41	54.97	13.78	59.05	5.69	17811	594	12437	728.2	306
Day13	1.875	2.625	243.39	11.54	178.46	15.93	153.69	19.99	138.74	26.17	29169	430.0	775.28	102.65	101.09	14.32	51.12	5.27	25464	708	13790	774.6	307
Day13	2.125	2.625	272.23	12.25	248.51	18.96	197.75	22.77	136.29	27.21	38550	508.5	609.57	100.85	31.89	13.22	57.90	5.74	19743	623	13668	760.1	424
Day13	2.375	2.625	320.16	12.84	195.88	16.85	191.95	22.31	146.36	27.23	35310	481.2	698.18	102.74	41.79	13.28	46.85	5.33	25198	706	13724	772.3	283
Day13	2.625	2.625	262.33	11.97	251.53	18.86	205.33	22.96	133.28	26.71	40566	516.7	796.15	108.95	35.58	13.16	57.39	5.63	17399	593	13381	759.0	327

Table A.3 Experiment IV - Copper Smelting pXRF and magnetic susceptibility data

Day	Easting	Northing	Zr	Zr Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Sr	Sr Error	Rb	Rb Error	Ca	Ca Error	K	K Error	MagSus
Day13	2.875	2.625	292.55	12.58	306.32	20.75	215.35	23.46	200.93	29.94	38691	507.4	641.71	101.82	66.91	13.95	64.58	6.07	15464	557	12734	735.8	427
Day13	0.125	2.375	322.44	12.71	299.26	20.36	217.30	23.27	134.10	26.63	41457	520.6	648.93	101.76	< LOD	16.22	81.81	6.50	3061	278	12405	718.5	299
Day13	0.375	2.375	459.32	14.77	347.35	22.04	304.68	27.03	178.74	29.01	42125	530.5	799.74	110.60	< LOD	16.61	65.21	6.01	4304	314	11169	683.5	383
Day13	0.625	2.375	372.07	13.79	355.00	22.58	219.61	24.24	228.43	31.68	48070	574.1	772.24	111.93	< LOD	17.00	67.83	6.30	4435	318	11066	680.4	412
Day13	0.875	2.375	357.47	13.57	308.89	21.08	255.89	25.67	142.00	27.83	46059	560.3	900.72	117.08	< LOD	18.12	62.02	6.04	5748	354	11389	690.3	345
Day13	1.125	2.375	307.97	12.58	380.99	22.92	226.60	24.03	161.63	28.07	44298	541.8	696.17	106.01	< LOD	16.00	65.03	6.03	4501	319	10422	662.9	443
Day13	1.375	2.375	341.55	13.10	213.17	17.50	160.71	20.93	164.77	28.05	38545	502.9	733.20	105.51	< LOD	18.89	58.52	5.69	10780	470	10719	677.3	329
Day13	1.625	2.375	335.77	13.03	271.66	19.55	256.46	25.02	146.00	27.25	38484	502.8	702.00	103.82	< LOD	18.70	65.08	5.91	8602	424	12577	723.9	351
Day13	1.875	2.375	321.76	12.76	266.24	19.16	181.01	21.65	158.35	27.33	36762	488.0	594.47	98.17	21.99	12.75	61.25	5.77	14312	533	11957	709.2	336
Day13	2.125	2.375	279.17	12.36	374.50	22.75	203.19	22.89	160.19	27.92	38721	506.6	586.96	98.69	62.35	13.83	62.94	5.98	25386	711	12335	737.5	453
Day13	2.375	2.375	278.23	12.60	264.27	19.66	187.38	22.61	159.36	28.50	41693	531.7	614.35	102.21	115.26	15.13	51.69	5.60	26455	713	13698	761.8	319
Day13	2.625	2.375	281.37	12.44	298.39	20.62	247.41	25.07	162.98	28.47	42434	534.8	655.64	104.64	41.44	13.45	62.19	5.92	19782	625	13164	748.4	346
Day13	2.875	2.375	265.88	12.10	346.03	22.06	166.77	21.67	175.99	28.92	43133	537.4	564.41	99.82	< LOD	18.70	61.08	5.93	7419	400	12616	728.7	1112
Day13	0.125	2.125	348.19	12.83	264.37	18.90	189.66	21.76	123.69	25.41	37534	487.5	783.15	105.83	< LOD	15.37	68.91	5.95	4452	319	11118	683.3	286
Day13	0.375	2.125	339.69	12.92	281.25	19.75	189.85	22.13	108.65	25.13	36049	485.4	726.36	104.37	< LOD	15.82	56.66	5.59	4190	311	11476	691.9	331
Day13	0.625	2.125	363.77	13.26	258.58	19.05	224.70	23.72	145.26	27.14	41770	522.1	717.18	105.74	< LOD	15.41	61.60	5.78	4640	324	11425	691.8	330
Day13	0.875	2.125	340.03	13.01	247.50	18.75	224.76	23.51	135.69	26.52	37835	498.5	786.23	107.36	< LOD	16.41	64.05	5.91	6129	364	11890	703.0	317
Day13	1.125	2.125	291.42	12.07	274.10	19.28	199.18	22.17	136.67	26.24	37537	488.7	803.21	107.02	< LOD	16.68	66.70	5.89	9284	437	10867	678.7	299
Day13	1.375	2.125	258.82	11.70	217.03	17.48	160.80	20.68	123.92	25.91	38419	497.3	734.31	104.80	< LOD	17.99	62.59	5.86	12681	509	13053	745.1	296
Day13	1.625	2.125	279.81	11.84	279.30	19.31	187.90	21.58	130.93	25.63	37367	485.2	668.63	100.36	< LOD	16.60	62.85	5.79	6119	363	11531	692.6	310
Day13	1.875	2.125	251.81	11.70	297.92	20.34	193.04	22.55	153.87	27.67	42078	525.5	894.22	113.80	< LOD	17.89	56.83	5.72	10077	458	12990	740.4	304
Day13	2.125	2.125	323.37	12.93	390.29	23.31	264.73	26.00	186.70	29.75	48776	573.1	910.47	117.87	< LOD	17.26	72.24	6.28	6847	391	14185	774.4	427
Day13	2.375	2.125	317.64	13.00	338.67	21.89	207.23	23.55	171.45	28.91	42979	539.8	623.71	103.00	< LOD	19.24	64.08	6.06	15765	567	13858	769.7	421
Day13	2.625	2.125	337.54	13.09	358.09	22.26	196.89	22.86	199.86	29.68	42507	531.3	589.97	100.29	< LOD	17.39	56.61	5.71	10756	474	13610	757.9	444
Day13	2.875	2.125	319.14	13.16	421.86	24.67	219.50	24.85	236.50	32.62	54820	617.8	433.92	98.30	< LOD	18.12	68.20	6.19	3396	285	10741	672.2	656
Day13	0.125	1.875	296.81	12.44	262.71	19.31	194.65	22.68	145.25	27.33	43466	535.9	665.12	104.23	< LOD	17.22	67.43	6.09	3980	304	11694	696.0	322
Day13	0.375	1.875	299.17	12.24	282.62	19.69	193.63	22.25	137.85	26.52	38187	497.2	779.48	107.18	< LOD	15.40	62.11	5.82	5339	344	11271	688.4	324
Day13	0.625	1.875	323.47	12.87	329.33	21.51	271.71	25.88	138.66	27.07	44739	546.5	860.56	113.89	< LOD	16.19	66.08	6.07	3864	301	10948	678.7	394
Day13	0.875	1.875	322.31	12.77	331.16	21.38	237.58	24.36	163.19	28.07	42142	527.8	753.78	107.75	< LOD	16.07	60.92	5.83	5224	342	11244	689.8	345
Day13	1.125	1.875	322.86	12.64	190.47	16.54	148.44	20.04	150.14	26.98	36350	484.6	607.91	97.92	< LOD	17.13	67.05	5.96	6645	383	13462	753.4	253
Day13	1.375	1.875	328.54	12.87	347.56	21.93	227.48	23.80	159.09	27.84	42274	528.6	856.51	113.15	< LOD	16.31	65.42	6.03	5113	337	11129	681.6	374
Day13	1.625	1.875	303.73	12.58	353.90	22.29	271.90	25.99	165.73	28.47	44162	544.3	778.59	110.60	< LOD	15.94	63.42	5.99	3891	302	11095	683.8	459
Day13	1.875	1.875	329.03	12.90	270.14	19.46	197.09	22.79	128.61	26.38	40213	515.0	1331.34	131.72	< LOD	17.58	68.50	6.13	6457	379	12850	739.9	298
Day13	2.125	1.875	334.94	12.87	210.12	17.11	169.40	20.92	123.96	25.79	36533	483.9	595.11	97.09	26.59	12.80	58.44	5.50	10270	465	14027	770.1	337
Day13	2.375	1.875	318.04	12.88	350.90	22.18	245.87	25.15	160.38	28.28	44865	548.7	740.44	109.30	< LOD	17.68	67.42	6.12	6808	384	12385	719.5	524
Day13	2.625	1.875	354.40	13.39	189.97	16.68	195.56	22.38	87.98	24.54	35581	484.0	877.21	111.60	65.02	13.85	63.16	5.91	15947	562	14660	779.5	645
Day13	2.875	1.875	289.21	12.42	210.05	17.64	151.46	20.86	144.92	27.41	40721	523.0	621.04	102.23	< LOD	17.40	66.58	6.17	6694	377	12678	720.2	291
Day13	0.125	1.625	314.00	12.87	304.61	20.61	217.05	23.34	155.67	27.61	39491	509.4	678.92	102.99	76.45	14.08	77.75	6.40	4012	308	11860	707.6	326
Day13	0.375	1.625	296.14	12.42	353.37	22.21	239.61	24.69	165.81	28.27	43839	540.9	709.88	106.72	< LOD	15.61	57.86	5.74	4254	310	10721	667.3	442
Day13	0.625	1.625	314.02	12.74	359.17	22.39	283.09	26.50	162.79	28.25	47023	561.0	1074.79	124.28	< LOD	16.01	60.18	5.80	3959	302	10390	660.9	421
Day13	0.875	1.625	309.16	12.50	349.97	21.82	222.27	23.36	126.94	26.07	38699	501.9	824.05	108.96	< LOD	16.29	68.24	6.13	4606	325	11314	693.0	326
Day13	1.125	1.625	314.84	12.56	346.36	21.74	192.72	22.43	141.94	26.86	40694	516.7	851.35	111.18	< LOD	15.41	62.52	5.85	3565	291	10519	668.0	342

Table A.3 Experiment IV - Copper Smelting pXRF and magnetic susceptibility data

Day	Easting	Northing	Zr	Zr Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Sr	Sr Error	Rb	Rb Error	Ca	Ca Error	K	K Error	MagSus
Day13	1.375	1.625	362.35	13.49	296.13	20.60	189.85	22.85	134.81	27.36	47185	565.1	883.38	116.70	< LOD	15.99	73.73	6.39	3448	287	11463	688.4	372
Day13	1.625	1.625	371.31	13.73	194.91	17.04	160.96	21.11	127.78	26.78	42605	533.5	767.25	109.13	46.52	13.52	76.64	6.46	7000	389	13487	747.3	311
Day13	1.875	1.625	329.41	12.94	253.23	18.99	146.87	20.26	134.19	26.81	36888	494.6	791.44	108.38	< LOD	17.40	65.80	6.10	6268	371	13200	740.5	305
Day13	2.125	1.625	305.20	12.60	148.60	15.08	148.59	20.17	81.32	24.08	37325	494.8	582.37	98.18	< LOD	19.10	69.15	6.11	10569	470	13948	767.1	256
Day13	2.375	1.625	308.26	12.84	302.87	20.92	243.42	25.24	156.88	28.45	44510	551.2	867.56	115.62	< LOD	17.84	62.39	5.91	6219	371	12480	725.3	614
Day13	2.625	1.625	320.80	13.34	190.06	17.23	163.78	22.04	119.97	27.07	47615	576.6	748.96	112.15	67.93	14.30	69.51	6.27	12807	512	14007	766.6	735
Day13	2.875	1.625	290.61	12.30	113.78	13.46	104.33	18.05	87.84	24.42	36072	486.4	522.89	94.60	< LOD	18.28	66.81	6.00	10230	460	15421	794.7	239
Day13	0.125	1.375	318.55	12.73	312.55	20.93	230.89	23.94	124.04	26.31	42211	527.8	730.10	106.66	< LOD	16.00	65.48	5.97	3905	302	11108	683.2	500
Day13	0.375	1.375	308.51	12.64	289.42	20.32	186.80	22.17	125.98	26.40	39045	511.9	705.18	105.01	< LOD	15.98	67.83	6.13	3872	300	11393	688.0	373
Day13	0.625	1.375	307.69	12.55	361.54	22.34	281.29	26.11	164.84	28.20	41696	525.3	799.08	110.90	< LOD	15.64	59.80	5.79	4395	315	10820	670.4	420
Day13	0.875	1.375	368.52	13.30	372.42	22.42	257.43	24.78	159.56	27.51	40185	510.2	807.28	108.87	< LOD	15.85	63.98	5.93	3926	300	10500	661.4	349
Day13	1.125	1.375																					
Day13	1.375	1.375																					
Day13	1.625	1.375	354.68	13.30	130.51	14.43	107.15	18.41	75.13	23.94	35762	489.1	416.52	89.47	< LOD	16.59	93.25	6.92	2659	272	15410	800.3	149
Day13	1.875	1.375	366.14	13.49	64.12	10.92	93.29	17.27	49.33	22.33	34650	479.5	836.55	109.42	< LOD	18.59	76.29	6.38	7191	393	15178	784.8	122
Day13	2.125	1.375																					
Day13	2.375	1.375	319.27	13.10	196.89	16.86	174.17	21.34	124.22	26.00	34414	474.1	743.83	105.04	219.12	16.82	68.58	6.11	23393	676	14471	782.9	578
Day13	2.625	1.375	224.41	12.48	112.46	13.38	140.47	19.38	89.10	24.18	26895	417.9	806.61	105.22	687.05	23.67	59.72	5.86	62042	1087	15501	834.3	694
Day13	2.875	1.375	308.14	12.43	221.22	17.59	150.79	20.27	112.23	25.23	36849	487.3	616.59	98.62	< LOD	17.18	61.67	5.84	7122	392	12657	729.5	313
Day13	0.125	1.125	333.26	12.98	326.64	21.43	195.73	22.86	205.29	30.13	42365	532.1	804.03	110.65	< LOD	15.54	74.25	6.34	3312	284	11322	690.3	411
Day13	0.375	1.125	330.98	12.99	194.95	17.04	155.24	20.73	85.19	24.33	36535	494.5	573.44	97.59	< LOD	17.15	71.52	6.26	3334	287	13599	744.9	270
Day13	0.625	1.125	290.12	12.46	376.98	23.06	238.05	24.88	162.19	28.48	47119	564.5	634.55	105.09	< LOD	16.59	56.22	5.75	3842	301	10962	680.4	428
Day13	0.875	1.125	326.27	12.77	293.38	20.24	195.50	22.44	143.30	26.89	41236	520.8	924.50	114.76	< LOD	15.77	57.29	5.61	4598	319	10442	658.6	356
Day13	1.125	1.125	368.67	13.30	221.95	17.76	164.44	20.98	117.55	25.64	38136	497.7	683.90	102.63	< LOD	15.78	63.86	5.84	4759	326	11597	692.3	305
Day13	1.375	1.125	314.63	12.77	298.36	20.58	187.30	22.65	145.67	27.62	44095	544.6	864.28	114.58	< LOD	16.67	68.54	6.20	4169	310	11214	684.3	377
Day13	1.625	1.125	341.50	12.95	243.93	18.57	152.19	20.47	143.61	27.03	37347	494.0	596.15	98.45	< LOD	15.88	60.97	5.78	7821	409	11801	708.5	297
Day13	1.875	1.125	269.16	12.34	118.50	14.02	113.24	19.19	93.56	25.60	43804	547.5	740.46	109.99	44.41	13.63	74.60	6.44	10168	461	13723	759.6	514
Day13	2.125	1.125																					
Day13	2.375	1.125																					
Day13	2.625	1.125	376.18	13.57	250.31	18.90	214.71	23.37	126.94	26.57	40657	519.0	620.06	101.23	< LOD	16.47	66.23	6.02	5450	349	12237	717.2	270
Day13	2.875	1.125	388.75	13.74	222.09	17.93	166.73	21.10	120.60	25.98	35588	485.1	597.54	98.21	< LOD	16.99	64.42	5.96	8388	422	13735	756.4	234
Day13	0.125	0.875	338.66	12.86	248.40	18.65	173.34	21.26	116.82	25.72	38756	501.1	698.56	103.09	< LOD	15.81	77.09	6.33	3569	294	12606	723.0	246
Day13	0.375	0.875	277.15	12.09	279.74	19.86	152.64	20.63	108.93	25.27	42109	528.1	667.74	103.34	< LOD	16.43	57.32	5.71	5377	344	10469	664.6	388
Day13	0.625	0.875	293.55	12.27	382.07	22.82	222.02	23.72	201.55	29.59	46703	552.8	649.27	103.50	< LOD	15.18	62.60	5.89	3244	275	9401	626.7	532
Day13	0.875	0.875	342.46	13.25	379.16	23.11	205.56	23.58	174.69	29.07	46867	563.2	769.46	111.68	< LOD	16.07	61.11	5.94	3538	287	9866	642.7	792
Day13	1.125	0.875	325.58	13.08	357.08	22.52	227.78	24.48	140.66	27.49	45908	558.7	749.46	110.24	< LOD	17.92	63.09	5.96	3468	283	10363	653.1	456
Day13	1.375	0.875	329.14	13.12	271.78	19.92	152.66	21.12	172.72	29.09	45574	556.8	612.21	103.40	< LOD	17.54	64.66	6.02	4926	327	10407	655.0	499
Day13	1.625	0.875	318.13	12.62	287.06	19.91	189.85	22.05	119.71	25.89	39914	508.9	749.47	105.67	< LOD	16.47	68.57	6.09	6221	369	11886	709.1	361
Day13	1.875	0.875	269.51	11.91	212.52	17.43	157.95	20.73	129.09	26.21	36780	490.9	586.04	97.39	< LOD	16.83	56.21	5.60	7781	402	10993	678.2	278
Day13	2.125	0.875	315.08	12.72	233.40	18.30	159.67	20.99	120.41	26.14	38845	507.0	797.72	108.60	< LOD	17.54	61.89	5.78	7073	389	12161	713.3	293
Day13	2.375	0.875	297.70	12.39	223.62	17.89	174.14	21.70	141.49	27.32	40879	518.0	628.10	100.99	< LOD	17.06	70.38	6.24	6444	376	12354	722.1	231
Day13	2.625	0.875	297.66	12.57	297.39	20.71	195.26	23.10	113.55	26.18	45136	553.5	573.48	101.28	< LOD	16.42	62.76	6.04	4747	325	10905	674.0	346

Table A.3 Experiment IV - Copper Smelting pXRF and magnetic susceptibility data

Day	Easting	Northing	Zr	Zr Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Sr	Sr Error	Rb	Rb Error	Ca	Ca Error	K	K Error	MagSus
Day13	2.875	0.875	301.17	12.23	255.29	18.59	168.91	20.85	119.93	25.35	35590	474.3	636.48	98.07	< LOD	17.39	62.15	5.72	6660	384	12866	739.0	283
Day13	0.125	0.625	312.94	12.41	286.15	19.61	292.77	25.75	177.25	27.84	36398	479.6	773.26	104.67	< LOD	17.11	58.06	5.58	4404	317	11134	684.1	345
Day13	0.375	0.625	356.65	13.74	377.41	23.47	250.04	25.90	186.43	30.42	48876	584.6	818.00	116.45	< LOD	17.80	63.95	6.10	4484	319	9872	649.3	580
Day13	0.625	0.625	311.33	12.72	296.46	20.58	186.00	22.47	123.74	26.59	42833	538.0	658.46	105.54	< LOD	15.89	61.21	5.90	4797	327	10891	674.3	479
Day13	0.875	0.625	304.55	12.44	341.93	21.64	232.02	23.96	116.79	25.62	43692	534.6	677.96	104.10	< LOD	15.98	64.53	5.91	4230	312	10784	673.0	407
Day13	1.125	0.625	338.13	12.96	354.51	22.05	223.16	23.78	150.96	27.29	42288	527.3	897.84	114.31	< LOD	15.70	60.80	5.83	4428	314	9652	636.3	462
Day13	1.375	0.625	289.30	12.49	275.23	20.04	202.88	23.57	155.75	28.48	51563	593.7	732.01	110.52	< LOD	16.94	63.32	6.02	6097	362	10487	663.2	319
Day13	1.625	0.625	322.21	12.59	285.74	19.76	209.32	22.79	145.72	26.84	38496	497.5	706.41	103.28	< LOD	16.16	60.78	5.73	6433	372	10725	674.3	359
Day13	1.875	0.625	355.26	13.28	285.40	20.02	237.42	24.36	164.51	28.08	41224	522.0	819.86	110.92	< LOD	16.84	68.92	6.18	4979	334	10698	672.6	359
Day13	2.125	0.625	316.96	12.64	319.18	20.95	228.17	23.83	142.22	26.94	43274	532.5	872.61	112.18	< LOD	16.24	58.19	5.73	5346	344	10785	675.1	522
Day13	2.375	0.625	313.92	12.59	341.56	21.61	289.19	27.06	817.91	49.26	46189	549.3	746.82	108.23	< LOD	16.09	62.36	5.82	5484	351	11664	704.8	390
Day13	2.625	0.625	327.12	12.69	265.49	19.11	156.13	20.61	149.61	26.99	39604	505.4	677.97	102.20	< LOD	16.72	59.08	5.69	6239	365	11262	684.1	316
Day13	2.875	0.625	304.50	12.64	267.09	19.64	140.30	20.31	154.86	28.00	41012	526.0	567.20	99.29	< LOD	16.76	60.00	5.88	5691	354	12296	715.1	444
Day13	0.125	0.375	323.52	12.81	400.12	23.39	229.23	24.04	198.54	29.54	41944	526.9	745.55	107.31	< LOD	15.99	57.58	5.74	5745	353	10441	662.2	404
Day13	0.375	0.375	312.50	12.59	516.59	26.25	170.46	21.30	172.68	28.07	42718	528.1	656.27	103.26	< LOD	15.85	60.81	5.87	3832	296	9515	632.8	460
Day13	0.625	0.375	346.76	13.17	353.02	22.18	172.40	21.66	138.87	26.90	43929	540.6	712.19	106.93	< LOD	15.63	61.06	5.78	3689	292	9906	645.0	459
Day13	0.875	0.375	296.77	12.73	399.62	23.95	158.61	22.03	152.50	28.52	53716	610.2	549.33	103.38	< LOD	17.24	61.14	5.94	3262	279	9927	647.2	413
Day13	1.125	0.375	366.01	13.65	324.31	21.70	141.86	20.78	183.66	29.68	48503	577.2	1278.28	133.93	< LOD	15.72	62.12	6.04	3981	303	10776	670.5	727
Day13	1.375	0.375	280.25	12.22	431.55	24.39	118.44	19.81	371.44	36.61	48430	569.7	484.50	97.03	< LOD	15.42	55.99	5.72	2854	263	9878	641.6	953
Day13	1.625	0.375	314.85	12.71	310.36	20.87	181.18	22.26	178.51	28.98	42367	530.6	633.63	102.14	< LOD	16.42	63.04	5.94	4846	329	10582	668.3	404
Day13	1.875	0.375	291.08	12.45	317.71	21.17	192.52	22.84	178.12	28.89	44765	547.8	649.74	104.58	< LOD	17.71	64.34	6.01	5426	345	11201	683.8	616
Day13	2.125	0.375	307.91	12.62	404.69	23.66	201.33	23.21	142.70	27.38	46593	558.8	786.84	111.52	< LOD	15.43	62.99	6.05	4469	318	10463	664.6	463
Day13	2.375	0.375	327.27	13.02	401.40	23.72	167.92	21.69	169.26	28.69	47681	566.2	531.60	99.84	< LOD	16.38	71.20	6.29	3316	283	10580	669.4	421
Day13	2.625	0.375	319.08	12.81	316.79	21.08	179.21	21.90	143.20	27.20	40622	519.4	498.51	94.60	< LOD	17.09	62.76	5.83	6241	364	11017	676.3	381
Day13	2.875	0.375	300.88	12.49	279.24	19.87	147.72	20.56	165.84	28.20	41829	527.6	487.19	94.85	< LOD	16.33	57.02	5.72	4553	322	11785	701.7	371
Day13	0.125	0.125	255.20	11.55	391.21	22.86	167.09	21.17	186.76	28.59	46337	546.0	537.51	97.06	< LOD	14.90	55.03	5.57	3628	288	9195	621.5	406
Day13	0.375	0.125	352.59	13.33	302.17	20.67	179.21	22.19	117.22	26.26	44022	543.8	715.86	107.45	< LOD	16.71	56.12	5.71	4428	315	10297	656.2	377
Day13	0.625	0.125	295.73	12.35	382.07	22.89	226.57	24.08	138.83	26.93	46059	551.5	701.48	106.23	< LOD	15.59	59.76	5.85	4101	305	9357	630.9	395
Day13	0.875	0.125	361.25	13.49	344.74	22.05	162.30	21.68	148.67	27.78	48318	571.1	854.62	115.65	< LOD	16.10	64.05	6.09	3144	274	10297	653.1	829
Day13	1.125	0.125	280.29	12.27	315.65	21.23	152.03	20.92	123.35	26.53	45138	552.3	593.59	102.23	< LOD	16.08	62.57	5.98	3672	291	10622	661.3	524
Day13	1.375	0.125	328.51	12.90	344.29	21.89	174.15	21.75	134.80	26.83	43193	535.7	605.83	101.09	< LOD	15.89	63.75	5.99	3755	293	10107	646.3	422
Day13	1.625	0.125	299.28	12.71	413.79	24.29	196.32	23.45	190.84	30.22	48611	578.5	676.72	108.45	< LOD	16.42	67.88	6.28	3492	289	10852	675.3	440
Day13	1.875	0.125	362.55	13.52	337.53	21.77	189.51	22.56	143.98	27.55	42491	533.1	653.05	103.90	< LOD	17.89	63.50	6.05	5871	359	11355	691.0	371
Day13	2.125	0.125	295.16	12.41	405.47	23.65	216.48	23.70	170.85	28.52	44846	546.7	702.66	108.34	< LOD	16.14	65.28	6.04	3805	297	10642	664.7	409
Day13	2.375	0.125	285.85	12.02	352.81	21.74	171.63	21.24	204.53	29.28	44532	533.7	711.60	104.64	< LOD	15.34	61.94	5.77	3820	296	9829	640.6	582
Day13	2.625	0.125	338.61	13.22	413.15	24.07	201.22	23.45	188.87	29.68	47048	564.3	737.86	109.41	< LOD	16.43	71.64	6.34	3263	281	10872	675.6	422
Day13	2.875	0.125	319.17	12.74	322.14	21.21	210.92	23.43	164.69	28.24	43875	539.0	755.50	108.89	< LOD	16.06	62.60	5.91	4403	315	10340	658.5	430
Day37	0.125	2.875	250.83	10.99	134.84	13.80	82.39	15.25	86.82	22.46	21789	363.7	378.01	78.12	< LOD	13.86	56.35	5.36	3373	301	19445	887.0	405
Day37	0.375	2.875	279.68	11.59	178.25	15.62	104.04	17.09	71.40	22.43	26239	403.2	524.52	88.31	< LOD	14.27	58.52	5.52	3844	298	12166	709.9	342
Day37	0.625	2.875	276.11	12.26	236.97	18.78	160.07	21.08	118.35	27.92	27874	438.7	719.18	104.25	< LOD	16.05	60.03	5.88	6153	344	8186	584.6	276
Day37	0.875	2.875	251.29	11.13	112.76	12.92	55.84	13.97	48.32	20.95	22920	376.5	650.54	94.33	< LOD	14.47	58.72	5.47	2562	259	12239	715.5	188
Day37	1.125	2.875	374.98	13.24	81.30	11.69	70.70	15.35	55.54	21.69	25672	406.4	448.94	85.85	< LOD	15.03	72.33	6.07	2703	267	13441	747.8	273

Table A.3 Experiment IV - Copper Smelting pXRF and magnetic susceptibility data

Day	Easting	Northing	Zr	Zr Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Sr	Sr Error	Rb	Rb Error	Ca	Ca Error	K	K Error	MagSus
Day37	1.375	2.875	50.43	5.75	55.43	7.93	77.30	11.45	31.14	13.55	10722	211.2	235.61	52.02	< LOD	10.49	18.74	2.88	5974	364	12548	727.0	173
Day37	1.625	2.875	169.50	9.98	88.42	11.75	88.90	16.11	86.00	23.41	28735	420.6	488.57	86.81	29.57	12.63	25.22	4.13	24977	693	12128	728.0	208
Day37	1.875	2.875	234.95	11.60	41.71	9.36	154.21	20.44	81.51	24.56	26576	419.0	519.96	91.09	105.66	14.71	37.63	4.83	37246	853	25911	1041.2	279
Day37	2.125	2.875	59.34	7.97	26.22	8.00	80.48	15.27	72.11	23.28	9041	239.9	243.53	65.35	115.24	14.41	22.74	3.93	31709	779	58708	1470.7	194
Day37	2.375	2.875	90.16	9.45	31.19	8.17	149.99	18.05	105.33	22.83	7634	215.3	300.36	66.90	578.90	21.09	19.49	3.84	83407	1220	23228	988.8	841
Day37	2.625	2.875	143.76	13.55	13.10	7.90	87.43	16.87	90.39	25.60	6330	217.8	680.70	96.96	1697.37	35.35	67.71	6.61	176224	1848	49665	1481.1	356
Day37	2.875	2.875	< LOD	17.34	19.64	8.07	118.50	17.89	77.08	24.45	2989	151.4	529.74	84.27	1997.88	36.73	47.67	5.70	164300	1753	52805	1492.4	193
Day37	0.125	2.625	341.82	12.62	49.91	9.84	61.04	14.32	42.89	20.09	26214	405.8	414.32	83.08	< LOD	14.81	71.48	6.00	2981	283	15901	809.2	292
Day37	0.375	2.625	329.27	12.56	162.93	15.38	94.91	16.71	62.71	21.91	32047	451.3	527.72	91.55	< LOD	14.99	63.74	5.82	2998	283	14462	782.2	458
Day37	0.625	2.625	272.12	11.63	214.43	17.14	151.29	19.71	95.86	24.03	31047	442.1	666.15	97.68	< LOD	15.11	61.76	5.63	9144	438	11637	709.8	258
Day37	1.125	2.625	299.57	12.19	109.69	13.13	102.21	17.24	77.26	22.61	31811	452.8	596.53	95.75	< LOD	15.49	86.15	6.51	5333	349	13264	746.9	279
Day37	1.375	2.625	320.99	12.56	180.03	16.09	121.88	18.50	79.48	23.69	31744	451.4	577.95	95.10	< LOD	16.68	54.31	5.48	9718	446	11527	700.2	367
Day37	1.625	2.625	311.36	12.49	207.46	17.20	155.03	20.04	102.28	24.13	31768	453.4	589.95	95.58	< LOD	16.99	54.41	5.40	11766	490	12527	729.2	362
Day37	1.875	2.625	289.18	12.40	85.70	11.99	101.86	17.97	94.22	24.65	30473	448.8	561.28	95.26	67.06	13.90	45.80	5.17	26069	710	12926	748.3	333
Day37	2.125	2.625	70.29	6.94	28.41	6.94	62.14	11.48	61.98	16.84	10991	226.1	250.16	56.15	62.00	11.50	14.68	2.95	51797	985	18626	893.9	220
Day37	2.375	2.625	81.84	9.56	29.84	8.32	117.97	17.19	117.14	24.26	13712	289.8	474.55	81.09	620.31	21.97	33.67	4.58	90623	1325	46129	1393.6	361
Day37	2.625	2.625																					1170
Day37	2.625	2.625	42.59	14.75	< LOD	12.01	121.95	19.77	98.59	27.57	6267	223.5	641.67	98.37	2978.03	46.80	49.76	6.32	172643	1824	52391	1511.1	415
Day37	2.875	2.625	40.57	12.65	16.26	7.81	122.40	17.87	75.89	23.08	3821	167.0	616.62	89.05	2328.32	39.19	55.44	5.97	185239	1906	57409	1592.8	261
Day37	0.125	2.375	188.37	10.77	94.42	12.99	91.22	17.62	37.88	24.14	26147	429.3	378.98	86.40	< LOD	14.90	75.45	6.49	2811	256	11745	682.6	106
Day37	0.375	2.375	545.06	16.04	80.81	12.16	65.32	16.08	51.31	22.80	32109	469.8	294.77	82.44	< LOD	17.17	76.24	6.46	4028	313	15300	794.2	317
Day37	0.625	2.375	364.83	13.19	127.94	13.96	92.60	16.66	83.21	23.06	26781	415.5	541.16	91.20	< LOD	16.96	74.24	6.15	8600	428	13365	753.6	350
Day37	0.875	2.375	294.82	12.05	158.44	15.05	116.97	18.01	85.57	23.04	29481	431.4	565.70	92.88	< LOD	16.35	70.58	5.96	7922	415	13864	766.3	353
Day37	1.125	2.375	318.79	12.41	62.44	10.65	68.95	15.28	48.81	21.13	27617	419.3	381.58	82.28	< LOD	15.88	81.16	6.37	4712	337	17025	838.5	329
Day37	1.375	2.375	275.03	11.75	174.15	15.79	115.72	17.82	77.43	23.26	27421	416.9	582.19	92.76	< LOD	15.87	61.29	5.61	13766	521	13741	756.3	333
Day37	1.625	2.375	258.97	11.24	86.16	11.53	82.22	15.32	57.79	20.63	20995	358.1	428.17	80.37	< LOD	16.18	53.58	5.20	11368	481	13784	760.7	321
Day37	1.875	2.375	257.47	11.78	113.79	13.46	97.20	17.17	96.70	24.46	24781	405.6	426.00	85.29	< LOD	17.93	57.38	5.61	18788	606	13729	761.8	459
Day37	2.125	2.375	172.91	9.81	95.42	11.98	120.02	17.09	68.84	20.77	20628	353.0	261.09	69.97	< LOD	16.76	47.49	4.95	34623	811	14290	783.5	294
Day37	2.375	2.375	58.47	7.18	43.29	8.19	92.55	13.95	146.66	22.23	8837	212.1	256.85	58.77	138.00	13.29	25.12	3.69	69043	1168	62501	1596.4	206
Day37	2.625	2.375	29.19	11.99	< LOD	10.98	147.73	19.20	86.09	24.13	2333	136.1	557.95	85.17	2060.13	37.04	83.17	6.86	176777	1852	60700	1622.0	335
Day37	2.875	2.375	58.83	12.25	21.68	8.29	182.74	21.42	125.09	26.92	6262	211.6	678.71	94.94	1881.77	36.02	44.93	5.52	170190	1800	46826	1427.4	293
Day37	0.125	2.125	275.76	11.46	27.20	8.14	25.74	11.87	< LOD	27.03	21491	365.7	1100.28	113.56	< LOD	13.50	54.05	5.28	1835	235	13051	735.7	68
Day37	0.375	2.125	381.01	13.91	47.45	10.24	58.67	15.57	< LOD	31.56	38289	516.3	914.53	117.31	< LOD	15.44	83.72	6.69	3694	304	11640	716.0	287
Day37	0.625	2.125	400.51	13.55	47.98	9.74	69.98	14.75	41.50	20.24	18889	348.1	364.68	78.31	< LOD	15.96	86.03	6.52	14250	549	12917	763.1	304
Day37	0.875	2.125	258.10	11.82	142.46	14.65	145.82	19.57	50.71	22.36	23385	391.3	557.96	92.38	32.11	13.06	60.38	5.72	17456	591	10975	701.2	224
Day37	1.125	2.125	433.43	13.97	50.59	9.89	65.23	14.65	< LOD	29.56	21757	374.6	1179.61	119.11	< LOD	14.91	87.31	6.56	16584	577	14179	777.9	382
Day37	1.375	2.125	279.38	11.68	93.46	12.08	89.15	15.97	58.23	21.77	23064	379.8	555.23	89.54	< LOD	15.80	42.11	4.84	15820	555	12197	720.6	460
Day37	1.625	2.125	236.69	11.12	175.95	15.70	134.36	18.73	121.98	24.48	29813	433.0	590.68	93.70	< LOD	16.52	60.92	5.63	13547	525	14455	778.7	358
Day37	1.875	2.125	281.71	11.87	147.24	14.54	128.87	18.34	91.79	23.95	24157	389.5	446.56	84.50	< LOD	18.16	49.63	5.18	21882	648	14434	781.1	742
Day37	2.125	2.125	219.62	11.19	148.44	14.68	159.73	19.76	132.34	25.46	24092	390.3	635.00	94.24	140.18	15.10	39.04	4.76	41169	893	15824	835.3	672
Day37	2.375	2.125	79.55	8.05	58.36	9.44	160.66	18.06	221.17	26.63	13736	273.8	490.06	76.59	195.00	14.87	22.57	3.64	58921	1059	16997	870.6	7992
Day37	2.625	2.125	136.92	10.05	52.62	9.86	72.51	14.78	67.09	21.93	9150	243.7	306.65	70.01	304.53	17.90	46.52	5.07	101844	1388	33976	1208.7	290

Table A.3 Experiment IV - Copper Smelting pXRF and magnetic susceptibility data

Day	Easting	Northing	Zr	Zr Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Sr	Sr Error	Rb	Rb Error	Ca	Ca Error	K	K Error	MagSus
Day37	2.875	2.125	210.76	11.22	136.55	14.05	139.13	18.72	152.39	26.31	21570	366.4	592.91	90.19	279.46	17.40	39.80	5.00	59638	1064	14796	815.7	400
Day37	0.125	1.875	330.06	12.43	35.45	8.82	51.67	13.68	33.17	19.50	26897	409.5	558.98	90.72	< LOD	15.53	83.24	6.32	2196	255	14982	787.8	111
Day37	0.375	1.875	282.24	11.31	159.81	14.62	55.72	13.25	59.18	20.16	22746	367.2	601.13	88.88	< LOD	12.66	49.94	4.97	3299	280	10285	659.7	281
Day37	0.625	1.875	217.72	10.19	102.35	12.01	83.12	14.70	53.32	19.42	21308	350.9	318.30	72.18	< LOD	13.38	56.89	5.11	18991	610	12699	740.4	
Day37	0.875	1.875																					
Day37	1.125	1.875																					
Day37	1.375	1.875																					
Day37	1.625	1.875	255.26	11.63	118.61	13.47	196.94	21.80	102.47	24.29	28204	426.7	686.18	99.05	< LOD	18.64	46.72	5.16	37980	853	11256	714.5	377
Day37	1.875	1.875	249.51	11.37	177.26	15.62	156.23	19.71	111.72	23.74	27464	413.0	521.41	89.06	29.20	12.65	55.86	5.32	23504	684	15353	813.7	490
Day37	2.125	1.875	279.57	12.26	215.45	17.84	161.05	20.92	89.80	24.94	31881	463.4	570.32	97.42	< LOD	17.61	55.07	5.63	16192	562	14074	764.3	525
Day37	2.375	1.875	210.71	10.94	104.23	12.38	70.23	14.37	48.31	20.10	18164	332.2	387.39	77.57	215.36	16.12	47.92	5.06	47931	956	16085	841.6	343
Day37	2.625	1.875	191.38	10.13	99.52	11.91	107.80	16.26	70.58	21.45	16188	306.9	301.30	69.68	88.01	13.43	40.48	4.60	48823	963	17470	873.5	347
Day37	2.875	1.875	172.57	10.03	68.55	10.34	79.62	14.53	117.56	23.07	12387	268.6	343.44	70.27	216.55	15.71	39.33	4.60	40090	884	18881	910.5	363
Day37	0.125	1.625	438.59	14.27	45.02	9.73	48.56	14.13	< LOD	31.19	26915	421.6	650.52	98.60	< LOD	15.28	75.57	6.22	1195	206	12953	732.1	68
Day37	0.375	1.625	266.63	11.47	99.88	12.44	71.89	15.17	60.46	21.50	27245	413.9	335.65	78.89	< LOD	14.29	62.37	5.61	1939	235	11824	704.5	340
Day37	0.625	1.625																					
Day37	0.875	1.625																					
Day37	1.125	1.625																					
Day37	1.375	1.625																					
Day37	1.625	1.625																					
Day37	1.875	1.625	226.34	10.81	183.16	15.53	173.78	19.94	107.25	23.24	24145	379.5	427.12	80.79	50.16	12.85	48.21	5.02	30346	762	12337	734.2	292
Day37	2.125	1.625	256.94	11.67	115.66	13.15	93.73	16.31	54.11	21.45	21830	369.0	509.37	86.39	126.11	14.71	52.35	5.32	41716	888	13410	770.1	327
Day37	2.375	1.625	279.17	12.97	114.47	13.73	97.05	17.78	69.34	24.09	33313	476.1	447.56	91.02	325.80	19.05	57.81	5.92	30711	776	15906	832.6	331
Day37	2.625	1.625	281.99	12.19	94.33	12.28	86.42	16.04	77.76	23.25	18069	340.3	410.01	81.03	138.90	15.12	58.86	5.67	43026	901	14331	792.9	728
Day37	2.875	1.625	66.80	6.79	34.45	7.50	34.00	9.91	31.20	15.70	9030	210.0	161.23	50.89	< LOD	14.49	24.49	3.49	29479	759	14801	805.1	338
Day37	0.125	1.375	279.41	11.67	38.39	9.09	49.97	13.73	< LOD	28.23	24019	387.6	380.81	80.25	< LOD	15.03	83.07	6.30	1508	227	14384	774.3	111
Day37	0.375	1.375	900.05	19.73	38.93	9.56	55.80	14.25	< LOD	28.33	20542	374.8	956.47	113.17	< LOD	15.38	56.23	5.61	4269	315	13317	742.5	479
Day37	0.625	1.375																					
Day37	0.875	1.375																					
Day37	1.125	1.375																					
Day37	1.375	1.375																					
Day37	1.625	1.375																					
Day37	1.875	1.375	221.90	13.24	29.94	9.08	163.62	21.51	123.05	28.37	11709	294.1	644.79	98.15	796.83	26.27	59.02	6.16	118827	1499	55496	1514.0	1221
Day37	2.125	1.375	214.98	13.41	29.31	9.10	197.04	23.01	161.63	29.56	11394	289.5	763.80	104.72	966.58	28.20	61.10	6.17	121377	1530	54645	1519.1	795
Day37	2.375	1.375	146.64	15.23	23.72	9.10	151.11	21.31	141.93	30.00	3923	183.8	778.26	105.99	2326.05	42.23	51.86	6.21	168621	1800	49492	1471.1	1183
Day37	2.625	1.375	259.24	11.76	117.56	13.43	109.32	17.66	68.76	22.48	26303	410.2	486.76	87.68	71.89	13.78	57.36	5.52	27928	738	15932	825.0	347
Day37	2.875	1.375	273.95	11.93	128.72	13.79	108.81	17.57	79.88	23.05	27077	413.2	566.76	92.34	88.43	14.04	52.27	5.31	32970	807	14383	800.1	427
Day37	0.125	1.125	316.99	11.82	48.90	9.42	41.07	12.64	55.04	21.11	19427	339.9	456.77	80.57	< LOD	13.45	52.85	5.14	1302	201	10589	659.3	47
Day37	0.375	1.125	391.79	13.14	20.24	7.63	46.85	13.10	29.36	19.38	19086	343.7	384.97	77.87	< LOD	14.43	82.63	6.27	1903	240	14789	776.5	320
Day37	0.625	1.125	182.33	10.04	127.78	13.52	408.47	28.81	130.02	25.31	23044	377.7	863.27	104.04	< LOD	16.29	42.48	4.85	12438	494	11399	693.9	354
Day37	0.875	1.125																					
Day37	1.125	1.125																					

Table A.3 Experiment IV - Copper Smelting pXRF and magnetic susceptibility data

Day	Easting	Northing	Zr	Zr Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Sr	Sr Error	Rb	Rb Error	Ca	Ca Error	K	K Error	MagSus
Day37	1.375	1.125																					
Day37	1.625	1.125	239.94	11.58	195.90	16.76	127.48	18.64	104.30	24.55	25446	407.5	592.68	93.65	70.54	13.89	51.27	5.34	33845	800	11898	722.3	185
Day37	1.875	1.125	68.89	14.53	< LOD	12.22	105.12	18.79	85.31	27.31	4528	195.8	599.62	96.57	2523.34	44.05	49.81	6.20	174891	1829	40838	1350.0	1343
Day37	2.125	1.125	168.19	11.60	14.76	7.65	192.31	21.68	200.78	29.04	12518	290.9	557.64	90.38	652.64	23.43	58.91	5.78	136207	1617	35294	1250.5	555
Day37	2.375	1.125	226.76	12.76	22.23	8.31	172.42	21.05	162.58	28.28	7794	236.6	622.54	93.32	677.63	24.11	50.38	5.58	168457	1793	16249	917.0	1450
Day37	2.625	1.125	292.45	12.12	99.78	12.48	81.50	15.77	67.84	22.20	23677	385.3	355.10	78.67	59.49	13.39	61.10	5.60	24966	694	16451	830.5	435
Day37	2.875	1.125	348.46	13.09	167.67	15.61	108.54	17.46	86.75	23.10	25005	401.1	595.28	93.28	44.42	13.24	57.05	5.59	30551	766	13443	763.0	446
Day37	0.125	0.875	440.85	13.81	24.18	8.05	42.61	12.86	37.15	20.31	20986	361.2	563.70	88.97	< LOD	13.50	66.16	5.75	1123	202	12782	725.9	407
Day37	0.375	0.875	360.62	13.16	62.13	10.73	57.07	14.83	37.02	21.13	29072	436.3	556.14	93.72	< LOD	15.43	69.50	6.01	3554	294	12985	734.0	1616
Day37	0.625	0.875	262.62	11.50	149.00	14.71	114.84	17.86	97.65	23.68	30924	442.4	696.77	99.42	< LOD	14.93	57.50	5.50	6215	370	12324	722.4	326
Day37	0.875	0.875																					
Day37	1.125	0.875																					
Day37	1.375	0.875																					
Day37	1.625	0.875	203.51	10.17	119.39	12.88	108.92	16.38	61.06	20.32	22009	360.0	441.65	80.49	< LOD	15.67	48.35	4.92	19130	610	13337	751.7	366
Day37	1.875	0.875	194.54	12.60	23.22	8.86	93.53	18.31	77.86	27.68	19284	382.8	729.58	107.48	528.92	23.26	69.12	6.51	105782	1409	55745	1506.1	1042
Day37	2.125	0.875	144.08	13.51	19.53	8.34	125.76	19.39	109.43	26.08	13343	312.1	800.55	106.18	1598.77	34.81	56.50	6.21	167561	1788	47514	1438.4	1027
Day37	2.375	0.875	177.62	12.21	18.51	8.10	177.07	21.34	134.81	27.37	5277	200.1	588.66	91.78	717.26	24.94	47.55	5.51	168788	1794	37683	1299.3	1028
Day37	2.625	0.875	262.83	12.60	83.80	12.17	102.75	17.55	101.08	24.91	23886	401.3	514.09	91.13	308.22	18.63	67.57	6.20	73275	1185	26667	1070.9	541
Day37	2.875	0.875	312.76	12.51	158.78	15.28	113.20	18.28	63.10	22.17	31784	454.7	524.07	92.96	< LOD	17.23	58.09	5.69	17717	591	13699	759.4	520
Day37	0.125	0.625	260.94	11.56	175.28	15.84	134.23	18.94	73.62	23.20	29775	436.5	686.18	99.08	< LOD	15.52	56.28	5.52	6992	378	11220	680.9	279
Day37	0.375	0.625	341.17	12.88	137.67	14.47	96.74	17.13	79.43	23.26	26730	418.1	582.08	93.80	< LOD	15.48	55.23	5.49	8339	414	12466	719.1	350
Day37	0.625	0.625	261.72	12.11	151.74	15.59	96.71	18.35	122.06	26.72	46308	568.8	568.91	102.74	< LOD	16.11	57.36	5.80	10741	463	10141	655.7	375
Day37	0.875	0.625	209.91	10.34	150.04	14.25	99.55	16.16	87.44	21.95	22459	365.2	477.81	82.09	< LOD	16.32	39.43	4.58	18636	602	11716	708.5	372
Day37	1.125	0.625	234.23	10.96	176.27	15.54	168.24	19.86	85.26	22.74	26292	403.0	978.67	109.42	< LOD	16.52	50.42	5.17	14042	533	13384	755.1	359
Day37	1.375	0.625	222.89	10.79	245.38	18.04	143.22	19.13	121.63	24.56	29392	426.7	643.49	95.49	< LOD	16.15	52.02	5.12	20134	632	12693	742.5	393
Day37	1.625	0.625	346.17	13.16	183.95	16.44	127.57	19.04	117.78	25.71	30635	449.9	664.54	100.21	< LOD	18.31	54.34	5.52	15935	570	12950	753.2	348
Day37	1.875	0.625	300.11	12.45	117.95	13.70	79.44	16.26	63.37	22.64	28861	437.1	614.34	96.92	< LOD	17.86	70.07	6.12	9892	458	14366	781.5	341
Day37	2.125	0.625	308.39	12.49	146.50	14.78	97.99	17.26	76.50	23.10	32839	459.5	501.26	91.36	21.48	12.70	65.73	5.92	11555	487	14061	768.4	529
Day37	2.375	0.625	225.72	10.84	144.85	14.36	100.50	16.69	71.77	21.50	25091	394.6	447.69	84.31	< LOD	16.42	52.23	5.23	16681	578	14060	774.0	440
Day37	2.625	0.625	232.89	11.52	189.66	16.60	115.82	18.17	106.47	24.68	30757	448.9	775.64	104.89	78.18	14.10	53.05	5.35	29776	759	12492	739.9	606
Day37	2.875	0.625	233.27	10.82	251.18	18.04	151.31	19.16	108.69	23.97	23996	382.3	478.22	84.41	< LOD	15.21	45.63	5.02	13494	515	9542	647.4	375
Day37	0.125	0.375	354.04	13.06	54.91	10.32	42.85	13.82	60.62	21.93	30736	448.2	371.79	83.50	< LOD	15.14	59.79	5.63	2933	277	15352	789.0	354
Day37	0.375	0.375	215.85	10.72	248.50	18.23	138.73	18.83	93.78	23.18	28268	421.5	544.48	90.65	< LOD	15.85	45.98	5.07	13270	511	10261	662.4	353
Day37	0.625	0.375	256.63	11.45	166.01	15.43	111.54	17.76	77.42	23.35	26186	408.9	428.97	84.66	< LOD	15.45	46.86	5.11	10179	448	10117	655.4	380
Day37	0.875	0.375	305.19	12.37	192.70	16.65	114.17	17.98	88.88	23.64	26938	417.8	544.76	91.84	< LOD	16.70	50.39	5.30	22461	655	12285	723.5	492
Day37	1.125	0.375	284.05	11.99	182.52	16.06	116.64	18.15	87.35	23.15	28451	427.1	625.58	95.98	< LOD	17.41	53.93	5.44	18031	599	12555	734.9	429
Day37	1.375	0.375	221.19	11.02	176.57	15.74	170.39	20.25	96.61	23.27	24460	392.6	520.58	87.84	47.21	13.14	48.16	5.12	21420	647	12150	725.0	435
Day37	1.625	0.375	371.00	13.56	251.73	18.95	119.25	18.51	104.14	24.56	32000	460.5	416.06	86.94	< LOD	18.34	54.19	5.54	17304	584	11541	703.1	427
Day37	1.875	0.375	342.80	13.06	164.14	15.69	113.54	18.08	87.47	23.87	27361	425.3	540.10	92.39	< LOD	17.40	60.97	5.79	17622	593	15949	820.2	386
Day37	2.125	0.375	281.54	12.75	168.56	16.63	116.26	19.42	96.39	27.04	27300	447.6	910.76	116.44	< LOD	17.95	52.56	5.70	11925	482	10646	673.4	368
Day37	2.375	0.375	276.96	12.25	235.81	18.49	160.97	21.25	169.30	27.80	44613	546.3	1216.69	128.97	< LOD	19.02	64.49	6.02	12039	498	13685	759.6	411
Day37	2.625	0.375	314.06	12.43	169.08	15.61	134.29	19.05	80.89	23.35	27768	422.4	724.39	100.56	< LOD	16.90	56.30	5.54	13438	523	14846	791.9	419

Table A.3 Experiment IV - Copper Smelting pXRF and magnetic susceptibility data

Day	Easting	Northing	Zr	Zr Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Sr	Sr Error	Rb	Rb Error	Ca	Ca Error	K	K Error	MagSus
Day37	2.875	0.375	163.61	9.48	138.81	13.80	99.31	16.45	97.08	22.96	28803	414.4	401.72	80.36	< LOD	14.39	41.59	4.73	13192	513	12987	738.3	597
Day37	0.125	0.125	105.83	8.45	86.91	11.71	111.93	16.98	42.14	21.67	13570	292.3	328.57	72.35	< LOD	13.30	35.41	4.50	10196	438	11804	691.5	327
Day37	0.375	0.125	185.00	9.63	193.45	15.60	115.20	16.51	89.04	21.24	19864	339.3	526.16	83.43	< LOD	13.03	41.30	4.57	8575	423	11726	707.2	346
Day37	0.625	0.125	243.88	11.24	281.64	19.58	157.17	20.31	141.40	26.76	36593	483.6	425.04	87.50	< LOD	14.15	51.56	5.31	5075	334	9968	655.1	325
Day37	0.875	0.125	189.03	9.93	183.29	15.34	105.18	16.19	61.38	20.23	18721	332.5	446.68	79.59	< LOD	16.41	35.92	4.45	7308	391	9637	646.2	350
Day37	1.125	0.125	50.56	6.80	47.37	9.12	71.29	13.98	37.19	18.60	12689	275.0	589.86	84.66	< LOD	10.69	15.20	3.24	17659	583	12217	719.7	355
Day37	1.375	0.125	283.15	12.14	237.62	18.38	144.50	19.99	115.28	25.06	32786	465.2	639.03	99.30	< LOD	16.33	55.46	5.57	10515	465	11454	698.0	325
Day37	1.625	0.125	233.72	11.10	205.84	16.90	118.18	18.04	98.89	23.88	28879	428.4	547.27	92.08	< LOD	16.05	59.97	5.61	12951	505	11911	707.1	358
Day37	1.875	0.125	246.73	11.27	204.77	16.76	123.74	18.19	88.95	23.03	27926	419.2	587.13	93.17	< LOD	16.71	50.33	5.22	13204	516	13047	742.7	541
Day37	2.125	0.125	258.39	11.79	229.29	18.17	123.63	18.90	110.22	25.44	31055	454.9	551.57	94.73	< LOD	16.18	51.11	5.46	8687	421	11524	693.8	323
Day37	2.375	0.125	243.77	11.03	183.07	15.79	140.39	18.70	94.48	22.84	28887	420.3	511.77	87.72	< LOD	15.07	51.18	5.13	8840	431	12670	731.9	318
Day37	2.625	0.125	187.16	9.70	150.35	14.01	123.61	17.11	73.39	20.40	25434	383.2	466.85	81.54	< LOD	13.89	39.93	4.52	11091	476	12582	729.1	1362
Day37	2.875	0.125	257.45	11.35	231.86	17.62	151.69	19.42	78.13	22.60	27128	411.0	647.02	95.28	< LOD	15.58	49.08	5.15	9459	439	12711	725.3	486
Day43	0.125	2.875	224.37	10.23	97.83	11.79	58.97	13.37	55.28	19.92	19179	332.6	358.60	73.63	< LOD	12.42	43.83	4.73	4095	304	9945	651.9	155
Day43	0.375	2.875	259.40	10.35	142.66	13.09	54.87	12.21	75.01	19.16	15489	285.3	302.46	65.50	< LOD	13.66	39.27	4.24	6393	380	11601	714.3	371
Day43	0.625	2.875	220.01	10.04	202.84	15.66	78.49	14.55	107.50	21.73	26556	384.2	555.32	84.88	< LOD	12.84	38.37	4.42	8374	419	10977	686.3	274
Day43	0.875	2.875	270.45	11.44	90.88	11.86	95.08	16.07	62.93	20.68	23123	376.6	409.71	80.26	< LOD	15.77	54.00	5.27	13982	533	13442	756.5	252
Day43	1.125	2.875	302.66	11.06	42.21	8.49	39.54	11.13	< LOD	23.32	13009	266.2	431.77	73.26	< LOD	13.18	43.60	4.51	10208	456	11451	702.9	257
Day43	1.375	2.875	207.38	9.59	39.64	8.22	89.21	14.25	39.19	17.19	14598	278.3	345.62	68.03	< LOD	14.20	60.79	5.05	19438	630	14122	789.7	208
Day43	1.625	2.875	74.30	7.29	47.81	8.70	49.27	11.66	42.90	18.57	9468	226.1	164.01	54.32	< LOD	15.03	18.88	3.46	15672	522	6032	519.0	248
Day43	1.875	2.875	29.23	5.83	28.99	6.74	30.42	8.85	29.11	14.18	5023	151.2	132.89	44.41	24.28	10.45	8.77	2.58	51925	986	23370	993.0	1988
Day43	2.125	2.875	58.67	6.81	67.79	9.25	70.70	12.37	75.19	17.81	14555	263.5	393.87	66.57	47.24	11.41	20.82	3.33	40122	873	14585	799.0	212
Day43	2.375	2.875	28.10	7.43	18.79	6.82	158.74	17.12	83.62	19.71	6002	180.6	294.37	61.59	432.05	17.99	23.90	3.82	76238	1203	44199	1346.7	449
Day43	2.625	2.875	84.86	12.55	< LOD	11.01	89.83	16.35	98.72	24.33	4065	174.0	778.35	98.61	1845.37	35.63	31.42	5.07	163104	1770	48441	1454.7	255
Day43	2.875	2.875	57.73	10.34	15.92	7.35	69.03	14.02	66.44	21.81	3820	159.4	282.53	65.39	1208.20	28.33	21.83	4.21	81539	1206	34727	1179.0	175
Day43	0.125	2.625	260.49	11.28	23.42	7.89	29.75	12.10	< LOD	29.31	22900	376.4	< LOD	89.20	< LOD	14.38	72.73	5.97	1442	230	16479	827.9	129
Day43	0.375	2.625	293.88	12.61	192.92	17.17	115.74	19.30	97.58	25.27	47023	569.0	445.70	95.07	< LOD	17.22	46.47	5.37	4032	306	9962	656.7	285
Day43	0.625	2.625	258.63	11.91	68.77	11.32	53.69	15.41	52.74	22.78	40612	526.4	496.68	95.71	< LOD	16.18	58.64	5.83	13074	510	11879	707.4	384
Day43	0.875	2.625	358.32	13.51	92.47	12.61	66.07	15.58	51.38	22.09	34193	480.6	919.46	113.69	< LOD	18.67	55.22	5.56	11588	486	10635	679.0	368
Day43	1.125	2.625	357.59	12.83	170.54	15.42	92.44	16.23	71.04	21.69	25914	401.8	506.25	87.78	< LOD	15.81	52.25	5.29	13066	512	12624	730.6	361
Day43	1.375	2.625	301.22	12.92	52.11	10.56	48.12	15.70	89.13	25.86	46110	567.5	636.08	106.18	< LOD	19.45	61.21	6.11	15896	556	10950	679.3	372
Day43	1.625	2.625	244.94	11.40	206.65	17.18	119.27	18.26	116.00	25.03	27063	420.7	563.65	92.92	< LOD	15.70	47.88	5.17	14276	533	11524	703.9	546
Day43	1.875	2.625	160.89	8.38	73.93	9.46	62.10	11.73	61.61	17.06	12266	241.0	366.71	64.20	< LOD	14.34	28.16	3.62	30679	778	15205	819.2	283
Day43	2.125	2.625	100.32	8.67	53.91	9.44	68.27	13.71	53.80	19.53	14019	285.4	356.66	71.61	174.87	15.00	26.45	4.02	43253	911	18791	903.4	242
Day43	2.375	2.625	25.99	6.97	18.45	6.76	40.47	10.94	33.53	17.70	2988	132.9	87.41	45.36	256.56	15.55	16.09	3.37	45016	897	38133	1199.8	286
Day43	2.625	2.625	< LOD	11.78	< LOD	8.10	30.94	9.20	44.57	15.56	643	69.9	202.61	48.68	1232.63	24.78	18.42	3.63	142570	1674	61887	1633.3	321
Day43	2.875	2.625	< LOD	13.86	< LOD	10.26	95.71	15.52	< LOD	30.23	1175	100.3	251.46	61.74	1143.07	27.61	27.90	4.45	123733	1533	57425	1546.8	173
Day43	0.125	2.375	455.73	14.45	20.03	7.80	31.82	12.72	< LOD	27.68	23754	395.3	234.13	72.40	< LOD	15.26	56.75	5.61	5349	352	15624	803.6	66
Day43	0.375	2.375	272.44	11.15	87.11	11.46	55.47	13.23	34.24	18.52	22710	365.9	386.14	77.26	< LOD	13.40	46.77	4.86	9004	433	12048	717.2	268
Day43	0.625	2.375	229.55	11.06	27.52	8.38	68.87	15.05	41.24	20.28	25345	403.2	310.47	77.87	< LOD	15.97	92.19	6.79	10621	475	17011	844.1	309
Day43	0.875	2.375	244.64	11.06	45.46	9.38	60.76	14.52	31.58	19.55	25896	400.9	218.61	70.61	< LOD	14.99	84.05	6.38	6410	375	14975	781.7	326
Day43	1.125	2.375	336.90	12.70	113.56	13.19	88.99	16.33	40.43	20.99	24537	396.3	469.91	86.53	< LOD	16.28	64.82	5.78	12287	492	13427	742.7	382

Table A.3 Experiment IV - Copper Smelting pXRF and magnetic susceptibility data

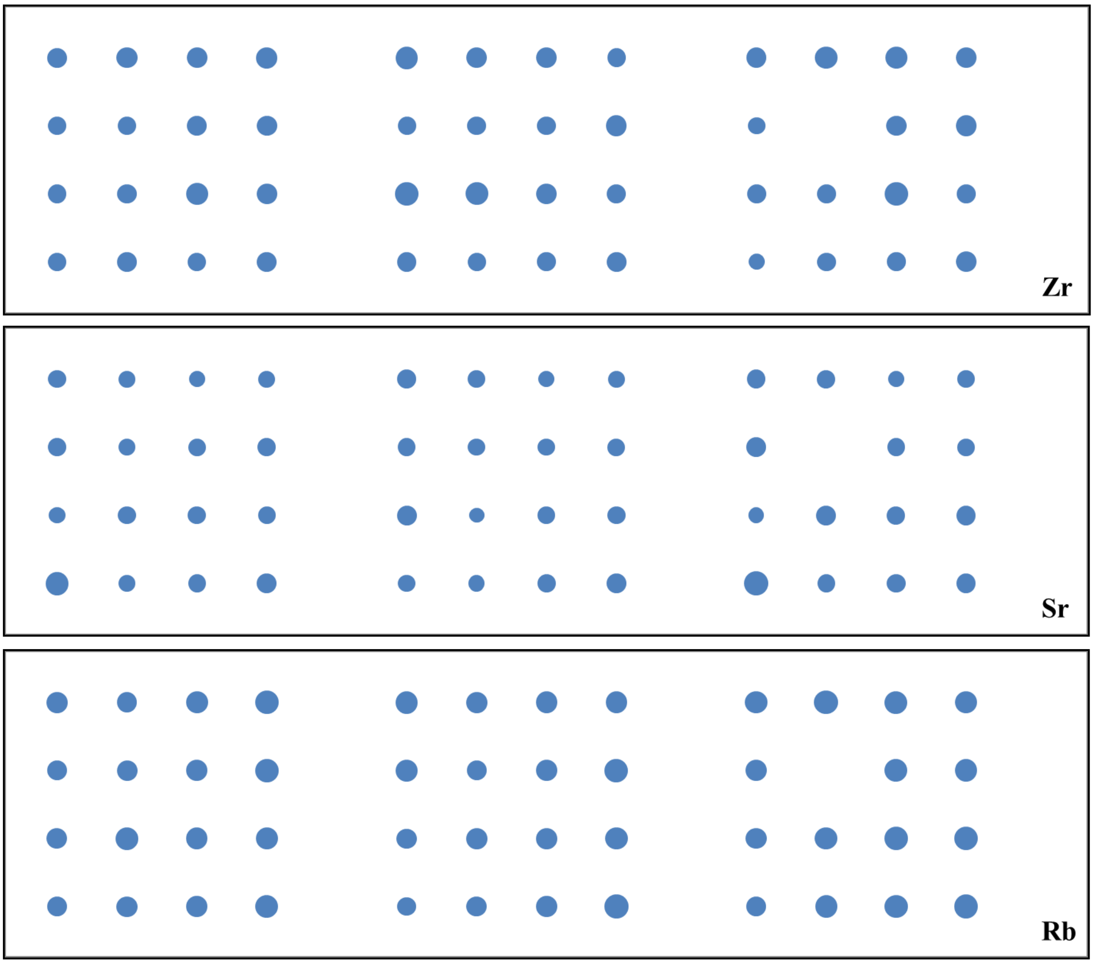
Day	Easting	Northing	Zr	Zr Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Sr	Sr Error	Rb	Rb Error	Ca	Ca Error	K	K Error	MagSus
Day43	1.375	2.375	420.70	14.23	139.92	14.71	93.66	17.03	85.49	24.04	27724	428.8	614.12	97.06	< LOD	18.87	57.73	5.72	23430	677	12811	746.0	369
Day43	1.625	2.375	341.98	12.83	118.84	13.52	95.87	16.68	93.36	23.41	25314	402.5	607.19	93.94	< LOD	17.46	49.71	5.32	29341	752	12300	733.6	362
Day43	1.875	2.375	223.52	11.10	134.41	14.11	108.30	17.39	82.48	23.81	23575	388.3	567.47	91.75	40.39	13.10	50.01	5.24	36093	837	15044	814.7	458
Day43	2.125	2.375	197.51	10.45	94.80	12.00	87.79	15.96	230.27	29.09	19889	349.2	329.47	74.81	58.52	13.20	33.87	4.30	36132	828	18522	885.1	202
Day43	2.375	2.375	342.32	12.56	16.16	7.10	63.13	13.54	< LOD	27.49	15675	306.7	384.50	75.68	113.25	14.16	38.01	4.57	52144	1005	33760	1182.7	160
Day43	2.625	2.375	< LOD	14.76	< LOD	10.01	65.21	13.33	148.69	23.97	1290	101.1	525.34	77.22	1657.59	31.60	21.48	4.15	191837	1929	56267	1572.1	187
Day43	2.875	2.375	< LOD	17.38	< LOD	10.73	79.72	14.85	66.17	21.45	1527	112.3	625.75	86.73	2113.37	36.65	28.32	4.82	178636	1860	55583	1558.1	184
Day43	0.125	2.125	348.45	12.61	23.60	7.91	29.29	11.72	< LOD	27.20	19807	350.5	139.54	62.29	< LOD	15.40	68.33	5.80	2658	274	15410	802.6	140
Day43	0.375	2.125	351.49	12.57	69.35	10.79	43.74	12.87	39.73	19.39	19624	347.9	396.06	78.90	< LOD	14.31	58.67	5.41	3731	304	14864	781.4	217
Day43	0.625	2.125	263.10	10.75	87.03	11.14	73.08	14.03	44.54	18.52	18031	318.8	513.00	80.80	< LOD	13.97	50.74	4.86	18163	601	15193	802.6	311
Day43	0.875	2.125	380.05	13.42	105.76	13.00	109.69	17.74	58.58	21.80	31237	453.2	3991.08	206.68	< LOD	16.00	68.79	5.91	17779	598	11782	716.5	251
Day43	1.125	2.125	199.29	9.63	123.02	12.58	98.50	15.12	64.22	19.36	18913	322.1	397.95	73.75	< LOD	13.24	42.18	4.50	23440	679	14439	790.1	395
Day43	1.375	2.125	242.69	11.38	127.36	13.82	97.43	16.76	119.66	25.05	21580	372.8	495.75	87.40	< LOD	18.47	52.00	5.29	29192	747	13924	776.1	410
Day43	1.625	2.125	294.70	12.26	145.63	14.73	121.78	18.22	91.13	23.23	25471	406.2	743.90	101.32	< LOD	18.35	52.19	5.40	20489	640	13418	765.1	471
Day43	1.875	2.125	215.54	11.01	113.36	12.92	127.87	17.85	124.14	24.21	18997	343.0	494.15	84.58	160.55	15.28	46.04	5.03	52250	1007	22215	981.0	1150
Day43	2.125	2.125	237.93	11.13	125.47	13.39	114.57	17.16	135.03	24.75	20312	352.1	558.64	87.47	74.56	13.51	44.44	4.90	62784	1107	30729	1146.2	460
Day43	2.375	2.125	154.33	10.83	70.20	10.86	151.97	18.91	149.52	26.13	8153	228.4	717.11	92.32	609.74	21.95	39.27	4.89	91389	1343	78798	1794.1	3086
Day43	2.625	2.125	< LOD	17.30	< LOD	10.94	127.73	18.31	84.49	24.71	2355	137.1	554.56	85.41	1926.17	36.05	30.14	4.97	163406	1780	70216	1727.9	170
Day43	2.875	2.125	55.53	9.44	45.54	9.56	126.19	17.50	98.25	23.48	3074	148.6	560.93	83.49	729.30	23.57	60.92	5.79	96299	1424	171252	2627.2	182
Day43	0.125	1.875	250.07	11.19	23.67	7.88	59.41	14.59	36.05	19.86	30071	434.6	564.92	92.25	< LOD	14.22	80.55	6.21	5881	363	13953	762.4	127
Day43	0.375	1.875	328.46	12.26	38.29	8.98	41.64	12.46	29.89	18.93	17369	328.6	487.42	83.51	< LOD	13.92	67.65	5.81	3736	304	13801	761.3	235
Day43	0.625	1.875	270.37	11.37	57.01	9.91	46.20	12.81	< LOD	27.25	18843	339.6	778.49	98.12	< LOD	16.01	46.38	5.02	11494	486	12859	740.4	
Day43	0.875	1.875																					
Day43	1.125	1.875																					
Day43	1.375	1.875																					
Day43	1.625	1.875	254.20	13.38	38.63	10.20	54.10	84.79	144.26	319.52	63121	231.4	720.86	18.79	233.66	1120.30	54.54	635.97	65663	37468	8150	636.0	525
Day43	1.875	1.875	296.81	12.60	101.27	12.92	107.62	64.81	935.27	187.35	25248	250.9	445.46	14.74	107.24	956.78	51.72	793.59	48494	40804	14229	793.6	325
Day43	2.125	1.875	137.24	9.30	54.50	9.28	44.93	50.31	61.99	94.64	6969	229.6	111.63	16.32	283.99	1173.33	28.70	1103.34	70701	36673	27780	1103.3	341
Day43	2.375	1.875	256.12	12.86	133.27	14.67	171.90	69.53	159.78	181.44	22243	218.3	600.63	21.14	462.02	1335.45	54.85	1335.69	94122	40150	43028	1335.7	418
Day43	2.625	1.875	88.21	12.80	41.27	9.88	132.07	67.34	98.56	86.38	5079	250.0	564.41	36.29	1864.15	1722.06	44.68	1811.52	152600	48598	78337	1811.5	330
Day43	2.875	1.875	138.89	9.62	77.24	10.71	68.52	53.34	59.03	99.57	7446	201.0	333.01	17.10	307.14	1449.57	31.71	1340.17	111182	41428	42547	1340.2	301
Day43	0.125	1.625	315.25	12.34	32.57	8.83	44.61	65.33	< LOD	186.06	26304	307.7	536.07	14.19	< LOD	285.62	67.24	680.62	3450	26839	11119	680.6	118
Day43	0.375	1.625	337.64	12.47	21.51	7.84	39.25	64.23	< LOD	167.36	21363	335.6	481.24	14.00	< LOD	287.73	70.73	726.52	3347	23661	12634	726.5	309
Day43	0.625	1.625																					
Day43	0.875	1.625																					
Day43	1.125	1.625																					
Day43	1.375	1.625																					
Day43	1.625	1.625	236.42	10.59	89.85	11.41	95.30	60.63	300.79	124.28	11635	197.6	371.57	15.95	< LOD	517.86	38.06	791.60	14139	25094	15552	791.6	
Day43	1.875	1.625	265.69	12.19	100.27	13.01	107.74	69.93	379.75	181.70	23308	241.8	539.39	14.09	67.89	772.18	49.73	772.46	31624	25236	13869	772.5	290
Day43	2.125	1.625	262.36	12.39	124.17	14.23	111.24	76.20	91.31	208.76	30392	237.5	597.92	15.52	129.11	1070.14	45.57	837.34	61144	32124	15811	837.3	280
Day43	2.375	1.625	241.80	11.52	164.31	14.66	74.43	59.39	< LOD	89.45	5541	192.9	333.97	18.57	390.30	1613.77	52.91	1197.89	136058	52304	31944	1197.9	326
Day43	2.625	1.625	248.31	13.69	107.19	13.88	122.31	72.69	141.13	196.88	25191	217.6	675.91	26.25	790.75	1338.68	57.48	1260.31	93601	37645	37478	1260.3	429

Table A.3 Experiment IV - Copper Smelting pXRF and magnetic susceptibility data

Day	Easting	Northing	Zr	Zr Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Sr	Sr Error	Rb	Rb Error	Ca	Ca Error	K	K Error	MagSus
Day43	2.875	1.625	307.71	12.66	104.06	12.88	110.52	64.75	73.84	182.25	25249	290.2	562.75	15.60	161.77	943.57	58.66	904.75	46264	29603	19004	904.8	322
Day43	0.125	1.375	329.35	12.37	36.26	8.82	47.11	59.62	38.52	168.30	21568	319.5	267.51	14.68	< LOD	417.23	67.77	783.78	8092	20861	14714	783.8	203
Day43	0.375	1.375	254.81	11.24	37.70	8.93	97.73	62.43	< LOD	176.43	23581	340.8	380.29	15.14	< LOD	384.13	91.84	784.09	6551	28600	14555	784.1	259
Day43	0.625	1.375																					
Day43	0.875	1.375																					
Day43	1.125	1.375																					
Day43	1.375	1.375																					
Day43	1.625	1.375	336.87	12.99	90.88	12.25	83.41	68.97	95.04	201.59	30358	290.0	695.12	14.08	83.95	671.48	67.23	832.15	22883	24082	16385	832.2	
Day43	1.875	1.375	46.41	17.45	< LOD	11.92	129.67	78.84	173.95	83.86	3248	247.8	899.68	56.92	4057.73	2014.10	28.98	1526.34	208771	52651	52132	1526.3	884
Day43	2.125	1.375	24.78	15.97	19.33	10.05	340.34	88.79	196.67	81.26	2859	231.5	1463.22	51.48	2958.76	1821.32	66.95	2089.93	166340	53934	103282	2089.9	841
Day43	2.375	1.375	54.61	12.53	12.13	7.69	100.93	65.10	102.22	86.79	4149	241.2	678.34	37.24	1944.73	1875.17	41.55	1540.76	179973	45555	53693	1540.8	1255
Day43	2.625	1.375	216.39	10.85	57.74	9.98	86.51	63.63	67.62	151.30	18064	254.4	486.69	15.10	164.77	961.30	51.65	1067.95	48110	31923	27303	1068.0	453
Day43	2.875	1.375	265.71	11.83	123.58	13.59	114.49	67.19	110.36	172.47	23296	266.7	488.56	14.40	107.16	970.07	52.45	872.33	49099	30372	17427	872.3	295
Day43	0.125	1.125	312.36	12.03	51.97	9.72	54.24	60.29	37.65	160.27	19713	310.4	611.72	14.56	< LOD	434.96	48.54	716.69	9011	26309	11950	716.7	166
Day43	0.375	1.125	392.56	13.41	29.75	8.55	44.75	63.14	53.46	107.59	18478	307.6	397.42	17.53	< LOD	631.13	60.48	749.00	20643	21903	13183	749.0	353
Day43	0.625	1.125	239.09	10.90	147.41	14.32	71.64	61.40	108.52	171.72	23510	306.3	510.31	15.09	< LOD	512.17	49.44	699.65	12958	29301	11372	699.7	
Day43	0.875	1.125																					
Day43	1.125	1.125																					
Day43	1.375	1.125																					
Day43	1.625	1.125	111.78	8.21	69.37	9.91	57.83	53.03	72.17	117.38	11868	247.7	268.14	11.51	19.35	665.92	47.40	784.68	23481	23403	14667	784.7	242
Day43	1.875	1.125	< LOD	31.77	< LOD	24.97	< LOD	231.51	< LOD	103.05	577	95.3	< LOD	65.53	1672.47	528.69	87.12	844.84	17743	25681	21623	844.8	1014
Day43	2.125	1.125	46.91	13.72	27.40	9.55	282.31	78.62	197.61	85.18	3591	222.4	1404.90	41.97	2281.73	1761.62	52.51	2052.74	158764	45265	101992	2052.7	544
Day43	2.375	1.125	89.83	17.61	< LOD	13.04	45.50	80.62	52.96	89.45	3352	236.7	355.75	54.98	3694.74	1992.59	63.78	1435.02	207431	53646	46096	1435.0	1499
Day43	2.625	1.125	287.49	12.69	87.07	12.27	72.17	70.93	78.81	198.01	27589	275.1	503.67	16.21	173.78	941.09	61.15	919.22	45429	26018	19401	919.2	333
Day43	2.875	1.125	279.79	12.17	154.44	15.18	127.26	69.60	95.33	187.47	25308	274.0	629.50	14.00	78.04	964.31	69.73	826.12	49149	36094	15639	826.1	387
Day43	0.125	0.875	358.70	13.08	42.93	9.62	59.86	70.12	< LOD	183.47	23937	293.0	421.37	14.71	< LOD	279.68	64.66	703.31	3298	22940	11964	703.3	693
Day43	0.375	0.875	191.30	9.92	108.99	12.52	56.77	60.06	57.00	161.03	20490	273.6	499.51	13.72	< LOD	410.50	44.85	767.14	7949	20825	14067	767.1	646
Day43	0.625	0.875	216.28	10.65	271.18	18.89	105.82	65.09	166.66	195.82	30081	245.3	497.66	15.07	< LOD	485.85	36.45	677.81	11723	22892	10708	677.8	366
Day43	0.875	0.875	229.41	10.61	123.59	13.16	90.50	59.82	78.38	168.27	22711	277.7	453.29	14.49	< LOD	561.27	35.14	675.03	15988	21372	10536	675.0	314
Day43	1.125	0.875	256.13	11.16	102.78	12.30	72.20	61.28	37.08	167.96	22534	279.6	529.40	14.92	< LOD	585.83	47.11	695.31	17332	23285	11130	695.3	560
Day43	1.375	0.875	202.43	10.22	333.58	20.30	119.53	59.04	191.67	179.07	25443	272.8	511.75	15.14	< LOD	515.30	42.62	683.68	13265	24135	10874	683.7	295
Day43	1.625	0.875	262.29	11.74	171.35	15.65	125.06	66.73	145.05	197.68	28863	262.9	870.52	13.27	51.15	757.29	55.51	835.94	29043	34885	16087	835.9	344
Day43	1.875	0.875	90.27	17.03	23.40	11.76	206.52	117.38	92.24	99.47	2654	172.7	810.70	47.09	1683.80	1137.79	37.33	1204.59	77766	32985	39581	1204.6	856
Day43	2.125	0.875	83.42	14.16	41.00	10.37	231.00	73.50	136.45	94.30	5159	271.7	712.18	41.87	2364.53	1845.94	79.65	1824.46	171607	58778	76979	1824.5	1154
Day43	2.375	0.875	< LOD	25.50	< LOD	11.95	134.26	78.63	76.62	71.01	2195	241.9	1040.88	56.68	4027.48	2035.71	30.12	1294.03	212298	42066	35443	1294.0	1024
Day43	2.625	0.875	327.09	12.93	60.68	10.61	64.53	66.76	46.62	213.58	33293	286.7	267.26	14.15	82.62	714.68	75.43	878.79	25759	23304	18247	878.8	329
Day43	2.875	0.875	314.97	12.87	146.33	14.86	116.01	68.74	58.96	187.20	24978	257.3	541.56	15.06	123.57	874.40	52.77	824.27	40330	28683	15737	824.3	401
Day43	0.125	0.625	371.70	12.77	31.11	8.35	46.16	56.89	47.34	143.55	16040	347.8	357.78	14.11	< LOD	267.08	62.85	812.50	2467	25344	15845	812.5	417
Day43	0.375	0.625	293.72	11.79	100.86	12.36	82.33	62.83	56.90	170.17	22408	288.8	746.13	15.02	< LOD	433.75	56.04	662.17	9200	29823	10173	662.2	378
Day43	0.625	0.625	287.33	11.70	126.12	13.48	74.83	59.96	70.38	168.23	21980	293.4	485.38	15.93	< LOD	460.88	39.83	670.22	10546	21895	10431	670.2	368
Day43	0.875	0.625	304.96	11.79	120.46	13.13	73.64	59.15	66.30	173.62	24177	261.0	374.84	14.19	< LOD	498.33	34.88	604.66	12512	25478	8264	604.7	359
Day43	1.125	0.625	258.32	11.41	141.63	14.36	100.79	64.00	91.84	181.24	25019	274.9	601.19	15.77	< LOD	564.24	48.21	692.95	16031	21195	11070	693.0	390

Table A.3 Experiment IV - Copper Smelting pXRF and magnetic susceptibility data

Day	Easting	Northing	Zr	Zr Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Sr	Sr Error	Rb	Rb Error	Ca	Ca Error	K	K Error	MagSus
Day43	1.375	0.625	131.52	8.92	168.67	14.60	65.45	58.51	106.26	161.84	21581	235.9	286.01	12.29	37.92	671.64	37.51	600.89	23571	28112	7872	600.9	355
Day43	1.625	0.625	213.56	10.84	131.52	13.94	91.52	65.00	86.98	207.50	32845	242.6	662.35	18.03	< LOD	735.98	43.47	713.64	28019	29752	11619	713.6	344
Day43	1.875	0.625	286.11	12.39	148.30	14.93	97.52	67.89	139.61	195.26	28396	271.0	543.66	14.51	96.41	826.00	49.97	817.12	35164	26484	15305	817.1	329
Day43	2.125	0.625	197.86	12.16	100.91	13.58	69.06	83.54	171.66	218.04	61031	183.2	951.45	19.98	343.77	920.04	66.29	1234.76	42294	30882	36574	1234.8	444
Day43	2.375	0.625	145.72	9.71	72.83	10.35	82.47	52.87	43.82	119.49	11651	230.9	266.60	17.88	382.98	1083.78	39.35	948.67	60244	31101	20078	948.7	530
Day43	2.625	0.625	287.42	12.36	121.11	13.79	76.14	71.61	106.60	201.76	28321	261.2	480.73	13.30	37.03	742.03	36.96	741.77	28416	23374	12535	741.8	320
Day43	2.875	0.625	233.03	11.17	179.10	15.82	92.10	64.92	98.03	189.78	26543	272.7	563.42	18.74	< LOD	660.63	54.61	767.61	22450	31591	13842	767.6	346
Day43	0.125	0.375	195.75	9.63	152.97	13.91	124.72	56.35	76.30	161.68	21775	287.6	399.85	11.88	< LOD	379.57	33.14	667.01	6806	21089	10521	667.0	469
Day43	0.375	0.375	239.92	11.11	180.30	15.94	108.90	65.11	69.48	222.52	38074	256.8	650.55	14.24	< LOD	462.00	46.88	640.27	10528	29659	9502	640.3	341
Day43	0.625	0.375	213.10	10.63	150.09	14.60	91.66	63.03	69.90	193.10	29388	265.2	602.02	15.57	< LOD	447.66	37.23	620.86	10033	20667	8884	620.9	335
Day43	0.875	0.375	182.57	10.02	146.81	14.38	70.61	62.28	71.95	172.23	23444	260.5	544.30	15.58	< LOD	457.36	41.19	665.14	10439	26772	10240	665.1	695
Day43	1.125	0.375	268.26	12.07	310.10	21.13	136.92	49.92	93.75	254.50	46613	275.8	472.89	15.25	< LOD	357.03	58.16	647.16	5911	22040	9820	647.2	395
Day43	1.375	0.375	258.41	12.71	181.84	17.72	102.27	86.26	113.35	334.15	69879	246.5	740.73	17.79	< LOD	552.87	48.32	604.51	15937	22332	8451	604.5	371
Day43	1.625	0.375	284.56	12.04	189.17	16.48	113.36	68.17	107.84	213.35	35345	278.8	603.92	16.72	< LOD	612.13	55.95	712.90	19298	25009	11939	712.9	364
Day43	1.875	0.375	321.94	13.06	157.69	15.54	105.64	73.03	253.34	205.18	30412	281.6	510.71	13.78	52.98	705.37	48.99	728.15	25742	33050	12069	728.2	379
Day43	2.125	0.375	232.46	11.14	151.01	14.75	104.63	66.46	96.75	189.73	26925	288.0	738.19	17.89	< LOD	674.88	56.88	818.14	23004	28275	15613	818.1	333
Day43	2.375	0.375	297.90	12.34	178.07	16.16	136.17	67.09	95.89	206.06	31237	296.5	853.39	16.25	< LOD	552.87	49.33	706.80	15421	29978	11614	706.8	358
Day43	2.625	0.375	288.44	12.27	160.86	15.46	93.80	66.70	70.89	207.40	31661	275.9	587.65	18.95	< LOD	703.89	55.03	770.79	25209	25169	13746	770.8	420
Day43	2.875	0.375	294.14	12.06	196.80	16.60	111.14	65.82	132.28	198.70	29663	289.9	609.17	16.41	< LOD	563.00	55.04	751.98	15877	22830	13312	752.0	434
Day43	0.125	0.125	186.79	8.37	189.37	13.47	99.22	47.94	76.53	136.67	19698	270.5	873.54	10.23	< LOD	406.68	33.52	608.54	8204	25807	8668	608.5	367
Day43	0.375	0.125	210.70	10.35	218.51	16.98	160.10	62.03	114.06	196.75	30779	257.0	716.74	12.94	< LOD	367.27	40.59	623.11	6447	20822	9090	623.1	385
Day43	0.625	0.125	194.02	9.68	140.65	13.43	99.27	57.46	63.52	162.42	22048	272.8	507.13	13.55	< LOD	457.15	36.59	651.87	10416	26764	9915	651.9	280
Day43	0.875	0.125	200.19	10.18	230.15	17.33	116.14	62.36	101.16	193.07	29448	267.6	1072.00	13.19	< LOD	393.62	41.29	635.50	7464	22388	9502	635.5	346
Day43	1.125	0.125	205.40	11.28	105.53	13.07	67.60	69.03	66.03	125.99	24740	247.7	452.39	16.31	189.30	1104.82	38.99	619.91	65327	38081	7599	619.9	408
Day43	1.375	0.125	293.51	12.21	271.77	19.43	158.58	65.15	120.51	199.87	30011	300.9	526.95	15.84	< LOD	490.17	53.41	705.40	12009	25592	11869	705.4	362
Day43	1.625	0.125	278.01	11.93	223.77	17.79	133.11	69.02	113.95	201.10	29410	272.0	539.20	15.41	< LOD	621.97	50.71	681.20	19856	25262	10634	681.2	359
Day43	1.875	0.125	198.21	9.88	148.84	13.92	95.26	59.98	91.34	164.61	22509	281.9	518.97	14.24	< LOD	634.47	37.63	738.34	20815	27154	12841	738.3	621
Day43	2.125	0.125	380.41	13.38	178.93	16.00	88.42	67.03	99.98	189.01	25905	275.8	516.21	16.85	< LOD	626.12	51.50	733.51	20453	26656	12803	733.5	342
Day43	2.375	0.125	291.83	11.88	193.76	16.28	106.88	66.78	84.78	185.28	27011	280.5	517.55	15.95	< LOD	610.46	45.55	694.71	18862	25501	11020	694.7	380
Day43	2.625	0.125	247.41	10.93	131.01	13.46	76.63	59.99	114.45	170.37	23420	287.6	440.53	15.36	< LOD	630.07	45.17	750.24	20190	25667	13007	750.2	636
Day43	2.875	0.125	285.04	11.94	240.03	18.09	137.87	67.23	102.73	198.25	29094	295.3	636.53	16.24	< LOD	551.24	55.72	695.76	15473	24145	11447	695.8	442



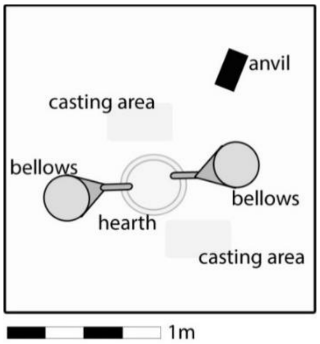
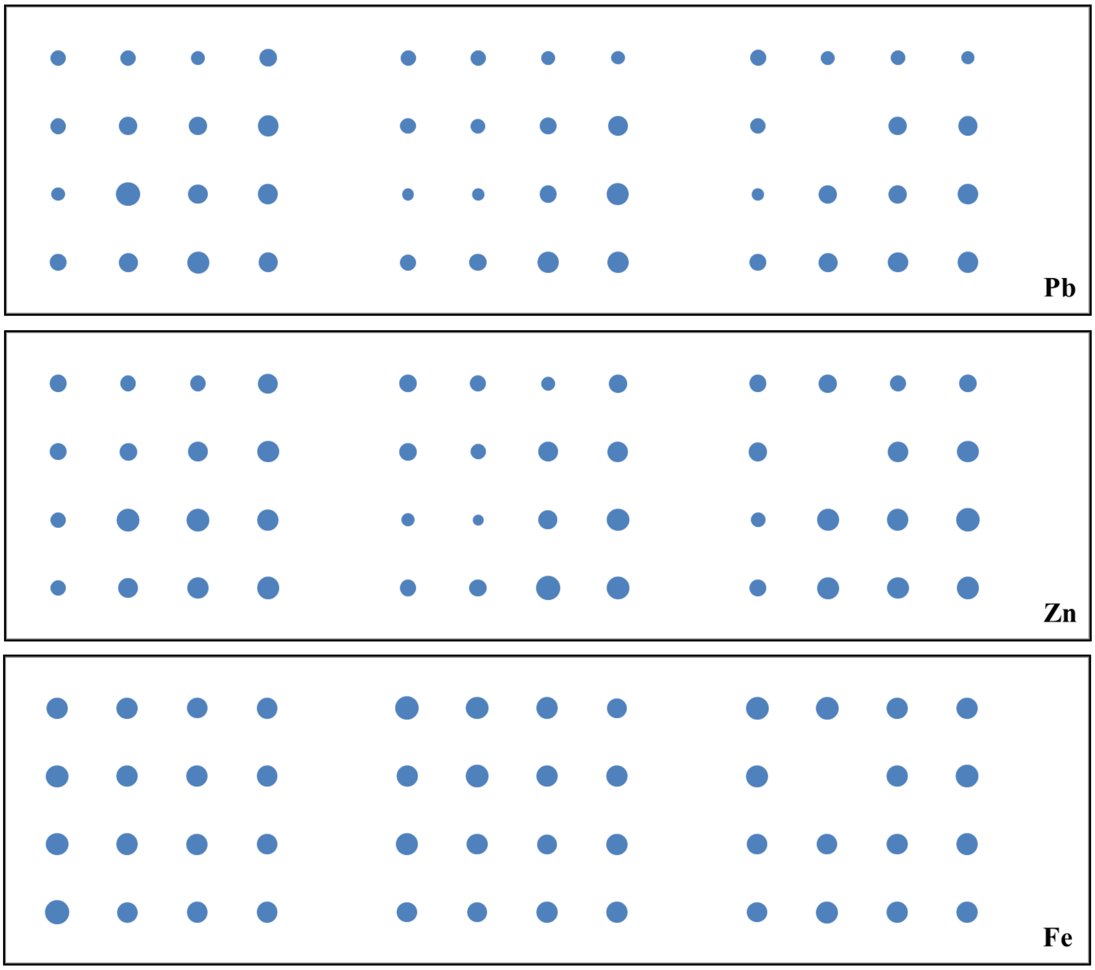


Figure A.7 Bubble plots of Zr, Sr, and Rb concentrations from Experiment V Site B, Ecclesall Woods, Sheffield alongside plan of site. *From left to right:* 26Oct, 9Nov, and16Nov.



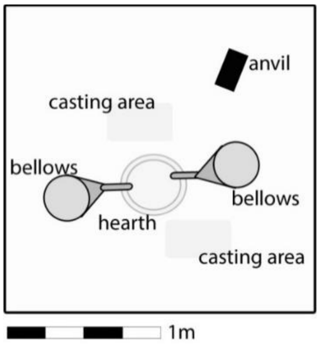
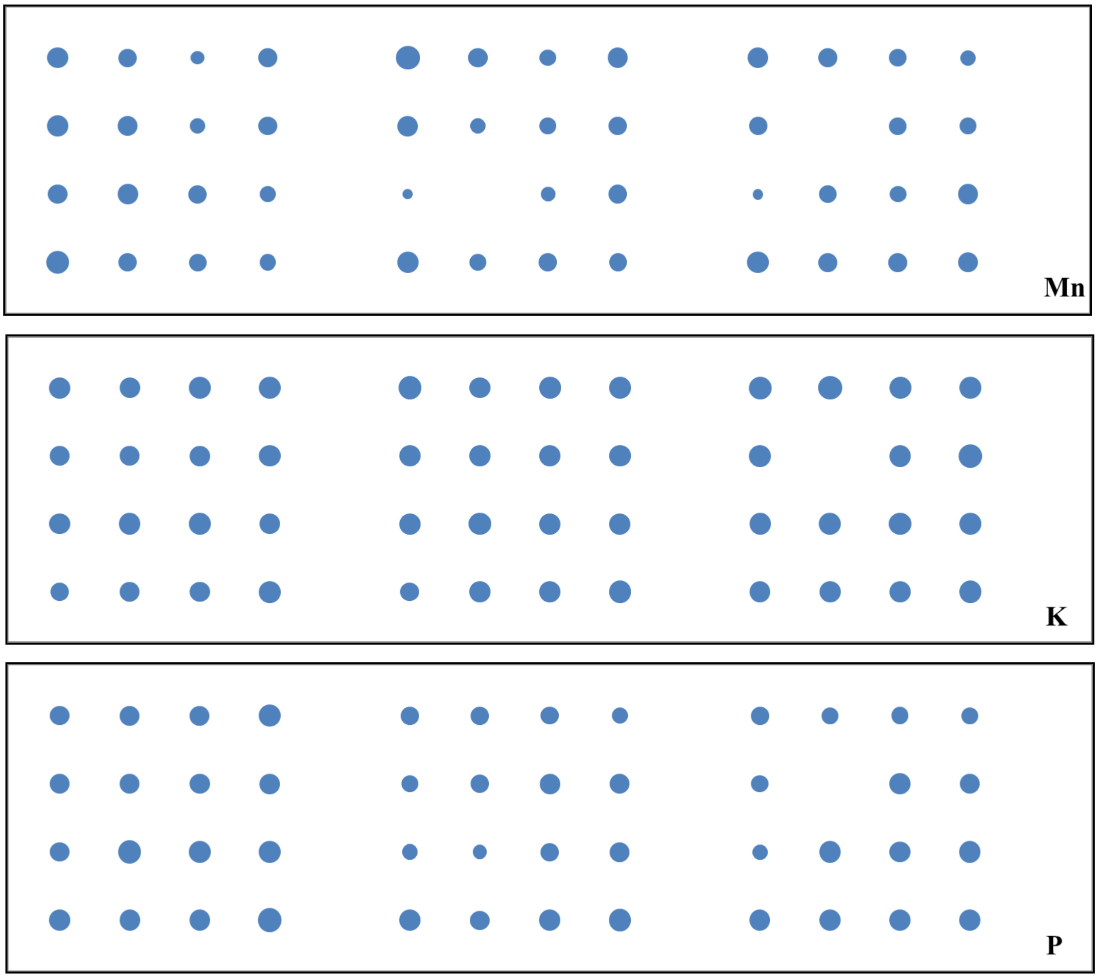


Figure A.8 Bubble plots of Pb, Zn, and Fe concentrations from Experiment V Site B, Ecclesall Woods, Sheffield alongside plan of site. *From left to right:* 26Oct, 9Nov, and16Nov.



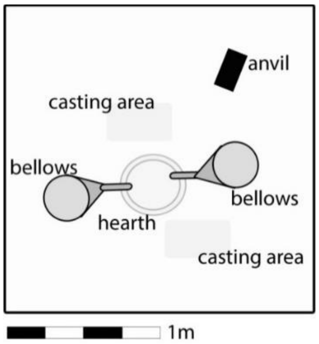


Figure A.9 Bubble plots of Mn, K, and P concentrations from Experiment V Site B, Ecclesall Woods, Sheffield alongside plan of site. ***From left to right:*** **26Oct, 9Nov, and16Nov.**

Table A.4 Experiment V - Copper Smelting & Casting pXRF and magnetic susceptibility data 1 of 1

Date	Easting	Northing	Zr	Zr Error	Sr	Sr Error	Rb	Rb Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Cr	Cr Error	Ca	Ca Error	K	K Error	P	P Error	MagSus
26-Oct	0.25	0.25	141.05	3.10	83.61	2.24	22.20	1.16	169.63	8.65	76.24	8.19	86.98	13.28	45754	328.3	850.06	78.46	121.97	40.21	10557	266.2	5393.4	220.95	1724.3	165.57	541
26-Oct	0.25	0.75	153.17	3.27	41.47	1.69	24.48	1.24	116.94	7.75	80.80	8.57	67.54	13.23	40071	316.4	606.82	76.79	150.81	39.35	10648	269.9	7432.7	254.71	1409.2	168.93	295
26-Oct	0.25	1.25	138.14	2.95	48.76	1.71	21.94	1.12	162.65	8.31	91.35	8.46	130.15	13.96	38811	294.1	724.98	74.81	128.09	41.21	14951	306.9	6383.7	238.94	1483.3	166.00	516
26-Oct	0.25	1.75	169.19	3.29	49.03	1.74	26.55	1.23	150.90	8.17	101.68	8.83	86.92	13.10	35642	283.9	680.36	75.08	121.95	40.13	13584	296.5	7631.5	257.85	1397.9	173.64	353
26-Oct	0.75	0.25	167.76	3.19	44.87	1.64	24.83	1.17	231.23	9.54	127.42	9.29	85.78	12.70	33359	267.7	543.33	70.72	119.41	37.20	11862	268.6	6532.9	231.67	1610.5	170.34	258
26-Oct	0.75	0.75	162.05	3.32	48.31	1.79	30.33	1.35	362.04	12.31	171.34	10.94	112.35	14.21	37630	301.7	692.00	77.46	125.60	40.30	12482	289.6	7744.7	261.28	1995.7	177.41	237
26-Oct	0.75	1.25	151.70	3.12	45.58	1.69	24.66	1.19	211.48	9.41	103.42	8.84	75.79	12.72	37017	290.3	610.42	73.65	130.03	39.41	13148	288.4	6371.5	236.44	1505.6	163.28	344
26-Oct	0.75	1.75	191.14	3.52	44.31	1.69	23.91	1.19	149.25	8.27	84.04	8.56	67.53	12.95	36531	291.6	532.94	73.04	96.63	41.26	10741	273.3	7013.4	248.38	1480.4	176.42	324
26-Oct	1.25	0.25	148.94	3.12	48.29	1.74	26.84	1.25	306.84	11.14	148.30	10.15	74.86	13.01	34955	282.5	491.34	71.55	130.45	36.98	10367	257.3	6939.8	239.85	1613.2	179.16	185
26-Oct	1.25	0.75	206.14	3.76	49.44	1.82	27.14	1.29	240.33	10.33	171.70	11.02	69.31	13.25	36591	299.1	546.15	75.24	129.21	39.31	13268	291.2	8025.8	261.10	1795.8	186.49	180
26-Oct	1.25	1.25	166.49	3.22	47.49	1.70	27.23	1.23	211.61	9.31	129.16	9.43	58.18	12.31	36315	283.9	379.42	68.33	111.43	39.01	11226	270.6	7112.9	245.49	1507.4	180.11	206
26-Oct	1.25	1.75	180.98	3.39	40.54	1.61	27.84	1.26	126.47	7.67	82.97	8.34	67.70	12.70	34126	278.8	301.20	67.52	135.02	37.06	10802	263.7	8070.3	256.92	1460.4	179.60	201
26-Oct	1.75	0.25	172.83	3.37	59.96	1.92	29.58	1.30	235.47	9.95	167.31	10.59	68.81	12.79	35511	286.5	452.05	71.26	134.69	40.94	15921	315.8	8082.6	264.01	2140.4	189.14	190
26-Oct	1.75	0.75	174.89	3.32	49.71	1.74	27.47	1.24	252.45	10.09	149.27	9.99	60.09	12.40	32340	268.0	441.42	69.93	196.70	35.79	14424	287.1	7140.7	241.20	1739.1	180.33	160
26-Oct	1.75	1.25	177.52	3.47	52.68	1.85	31.59	1.37	278.73	10.92	158.29	10.63	78.66	13.48	34657	287.4	552.81	74.41	135.47	37.14	13613	283.6	7741.9	249.66	1579.3	187.34	167
26-Oct	1.75	1.75	198.28	3.74	44.41	1.76	31.77	1.40	197.79	9.67	132.92	10.26	58.88	13.19	35785	301.2	598.70	77.97	122.84	38.72	10976	268.0	8442.6	261.18	1791.3	195.38	143
09-Nov	0.25	0.25	164.36	3.17	46.60	1.67	19.78	1.07	165.52	8.31	88.81	8.35	93.12	12.97	33206	268.3	711.82	74.29	115.15	37.63	14508	286.6	6034.5	221.12	1655.7	170.47	425
09-Nov	0.25	0.75	227.10	3.90	60.42	1.96	23.13	1.19	96.30	7.11	55.82	7.68	102.30	14.01	37885	300.9	176.96	66.44	137.69	37.29	7765	238.4	7597.3	254.18	930.8	179.61	200
09-Nov	0.25	1.25	146.95	3.11	49.06	1.76	27.95	1.27	157.34	8.42	103.25	9.01	133.49	14.47	37488	295.6	684.22	76.05	126.99	39.39	13134	292.1	7473.3	255.88	1081.0	164.53	400
09-Nov	0.25	1.75	220.61	3.92	54.74	1.91	29.85	1.35	149.65	8.53	106.19	9.49	136.16	15.19	43778	332.9	920.58	83.30	199.82	41.46	12293	291.9	8979.0	284.05	1243.3	191.81	410
09-Nov	0.75	0.25	143.58	2.97	42.44	1.60	23.73	1.14	185.18	8.68	101.39	8.71	97.68	13.09	32694	264.8	464.34	69.01	117.10	39.02	11316	271.1	7577.5	250.99	1372.7	175.77	215
09-Nov	0.75	0.75	221.99	3.82	35.46	1.55	26.06	1.25	96.96	7.11	41.08	7.18	97.13	13.77	34911	287.1	< LOD	126.07	149.80	35.72	4216	197.6	8234.8	261.17	783.5	177.93	190
09-Nov	0.75	1.25	155.74	3.18	45.25	1.69	23.23	1.17	133.61	7.86	77.93	8.19	117.46	14.03	40239	305.3	377.68	69.57	184.62	38.52	11289	273.4	7248.5	252.56	1274.1	178.87	374
09-Nov	0.75	1.75	176.24	3.45	49.52	1.80	26.70	1.27	153.95	8.50	90.62	8.84	119.21	14.35	39448	309.1	612.07	75.80	155.22	38.66	12501	286.1	7266.5	254.73	1245.4	175.62	355
09-Nov	1.25	0.25	153.30	3.18	50.63	1.79	27.15	1.26	280.95	10.79	190.95	11.18	107.20	13.89	34621	283.7	564.56	73.64	107.72	37.97	15146	298.6	7383.3	246.90	1683.9	181.66	184
09-Nov	1.25	0.75	180.12	3.34	46.94	1.69	26.52	1.21	184.33	8.74	120.33	9.26	94.69	13.20	31860	264.1	346.55	67.29	133.81	36.81	10862	262.7	7632.1	250.72	1253.9	172.71	150
09-Nov	1.25	1.25	156.30	3.20	45.90	1.71	26.20	1.24	179.55	8.88	127.27	9.64	82.20	13.21	34894	284.2	466.73	71.60	127.61	38.95	11664	275.7	7836.4	257.26	1565.9	187.79	174
09-Nov	1.25	1.75	184.10	3.49	41.67	1.66	27.09	1.27	121.55	7.70	65.15	8.03	88.57	13.50	37265	297.7	432.76	71.76	115.53	38.70	8767	249.9	8297.9	262.20	1219.3	183.06	220
09-Nov	1.75	0.25	166.61	3.34	57.66	1.91	32.83	1.38	280.93	10.86	169.40	10.77	122.92	14.47	35214	288.5	506.72	72.96	185.92	37.31	15787	310.4	8336.7	268.55	1843.6	202.06	176
09-Nov	1.75	0.75	155.79	3.22	50.11	1.79	29.17	1.30	302.13	11.19	166.22	10.66	90.35	13.53	35882	290.0	560.69	73.88	140.92	37.89	15029	300.2	7538.7	251.90	1467.9	184.04	159
09-Nov	1.75	1.25	182.88	3.52	48.35	1.79	31.69	1.37	242.66	10.32	139.25	10.19	111.58	14.39	36400	297.0	529.61	74.60	156.53	37.19	12879	285.5	7952.5	261.76	1444.0	187.22	162
09-Nov	1.75	1.75	150.89	3.15	44.80	1.70	26.92	1.25	116.23	7.50	110.90	9.22	90.16	13.45	31051	268.7	648.08	75.66	104.62	36.49	22461	351.0	8147.2	258.63	1014.8	173.66	138
16-Nov	0.25	0.25	115.11	2.82	87.72	2.27	23.18	1.16	170.69	8.56	101.20	8.84	96.73	13.31	32550	270.4	751.88	76.43	226.86	40.27	20341	339.9	7265.6	247.72	1633.4	173.36	523
16-Nov	0.25	0.75	160.88	3.23	39.14	1.60	25.70	1.22	100.78	7.09	72.06	8.06	64.91	12.60	34949	284.4	191.81	66.11	265.92	37.71	6071	217.4	7808.4	252.18	870.4	171.20	220
16-Nov	0.25	1.25	133.22	2.97	59.70	1.90	26.97	1.24	145.41	8.07	119.51	9.37	152.11	14.83	38740	297.9	545.22	72.73	234.37	40.60	16559	316.0	8135.9	262.71	1111.9	174.53	596
16-Nov	0.25	1.75	173.12	3.46	53.56	1.88	29.00	1.33	161.95	8.76	99.40	9.16	123.02	14.76	41369	320.9	649.37	77.46	144.98	41.16	11309	283.4	8645.7	276.98	1277.5	189.91	427
16-Nov	0.75	0.25	150.97	3.19	48.52	1.77	28.88	1.30	229.87	9.95	162.83	10.66	105.63	14.06	38602	303.8	590.42	75.06	192.06	39.08	12158	282.4	7673.5	258.76	1746.3	177.77	307
16-Nov	0.75	0.75	151.91	3.08	60.20	1.87	29.10	1.26	213.84	9.26	159.56	10.14	132.78	14.08	33507	270.4	498.96	70.35	314.94	40.85	23798	358.6	8121.6	256.62	1751.4	187.78	398
16-Nov	0.75	1.25																									
16-Nov	0.75	1.75	217.83	3.91	52.71	1.89	33.26	1.42	122.45	7.95	111.65	9.64	124.22	15.01	41607	325.3	604.89	77.80	225.63	40.70	12337	289.7	9628.3	288.75	1083.4	192.14	270
16-Nov	1.25	0.25	159.87	3.27	53.21	1.84	31.13	1.34	257.06	10.43	159.03	10.54	80.48	13.29	35362	288.9	584.07	75.07	279.53	38.37	17187	311.6	7291.6	244.84	1656.8	174.66	257
16-Nov	1.25	0.75	246.43	4.13	51.86	1.86	31.16	1.37	214.10	9.87	154.39	10.66	70.36	13.33	35003	293.2	442.89	73.93	233.28	39.73	12637	285.9	8572.1	268.85	1612.5	190.39	162
16-Nov	1.25	1.25	174.55	3.38	49.62	1.77	29.38	1.30	213.33	9.59	141.77	10.05	60.35	12.70	36322	291.2	495.82	72.63	171.60	38.86	13269	288.0	8035.0	259.30	1628.0	183.77	190
16-Nov	1.25	1.75	202.52	3.69	40.77	1.66	29.81	1.33	129.84	7.98	91.31	8.82	91.46	13.74	35451	292.8	495.77	73.85	138.70	36.48	13199	283.1	8130.0	258.22	1138.3	179.07	223
16-Nov	1.75	0.25	177.27	3.50	58.81	1.96	33.15	1.41	280.21	11.03	167.11	10.96	84.91	13.70	36215	297.4	660.88	77.47	118.24	37.80	15441	301.5	8286.3	259.70	1659.9	196.10	169
16-Nov	1.75	0.75	162.84	3.33	59.28	1.94	33.16	1.39	277.44	10.86	182.92	11.14	118.02	14.40	36992	297.8	662.63	76.80	187.74	37.61	17374	316.2	8139.9	259.12	1731.0	185.53	218
16-Nov	1.75	1.25	184.76	3.69	46.83	1.84	29.25	1.38	245.49	10.81	154.88	11.02	72.77	13.90	39787	325.6	471.12	76.78	198.08	38.47	12284	281.9	9294.8	277.12	1517.1	193.61	176
16-Nov	1.75	1.75	185.35	3.52	46.88	1.75	27.38	1.28	117.29	7.63	106.49	9.25	81.42	13.51	36615	296.7	386.40	71.50	204.35	38.84	14074	296.4	8136.4	263.38	1065.8	194.27	270

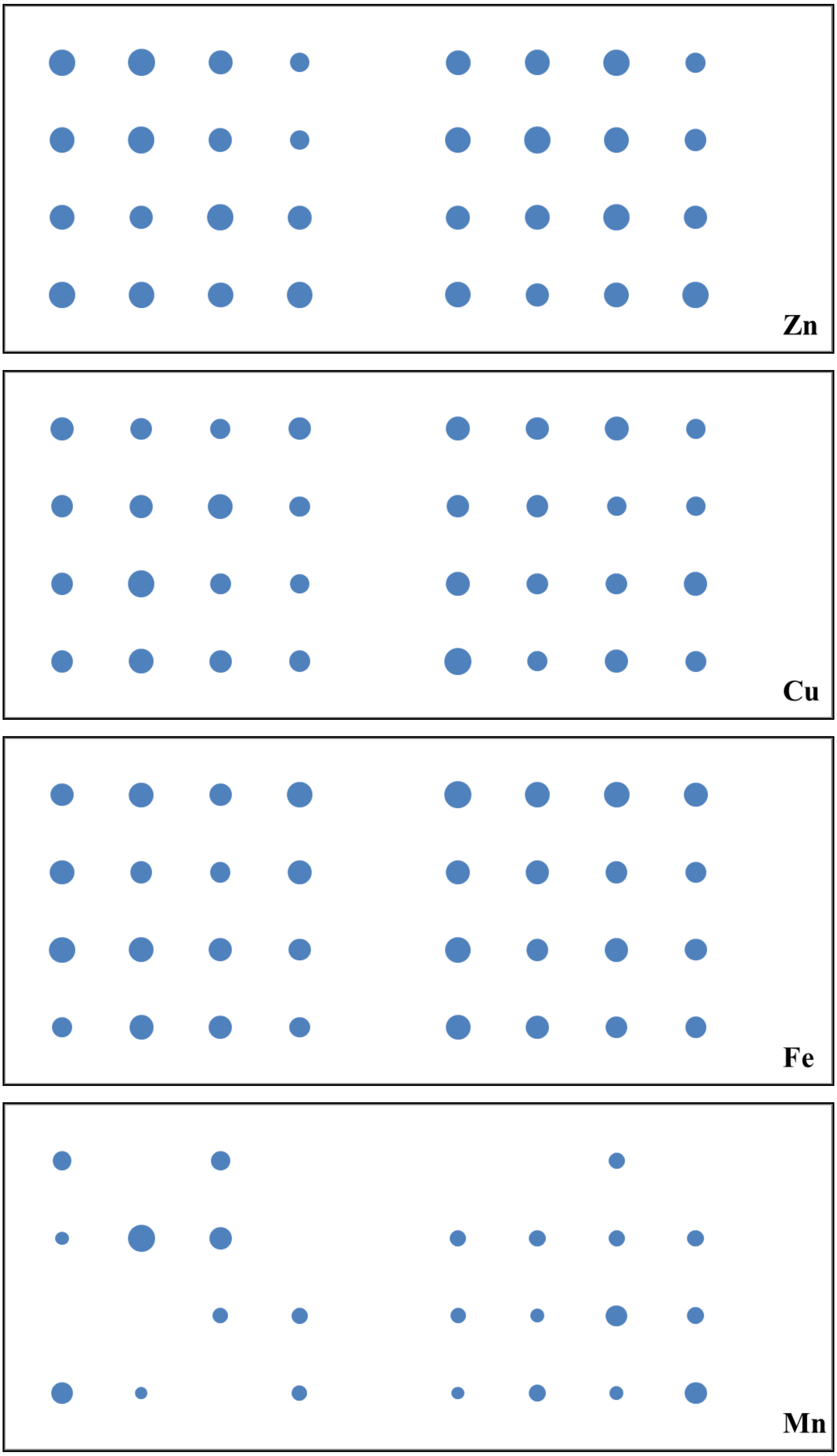


Figure A.10 Bubble plots of Zn, Cu, Fe, and Mn concentrations from Experiment VI Site C, Ecclesall Woods, Sheffield. ***From left to right:*** **AM and PM.**

Table A.5 Experiment VI - Cooking fire pXRF and magnetic susceptibility data 1 of 1

Date	Easting	Northing	Zr	Zr Error	Sr	Sr Error	Rb	Rb Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error	Ca	Ca Error	K	K Error	P	P Error	MagSus
16-Nov AM	0.25	0.25	46.29	1.61	21.87	1.06	7.96	1.00	260.98	8.59	230.34	10.05	86.25	10.92	10019	126.0	631.54	62.14	21430	301.3	3355.4	154.07	1991.5	156.40	92
16-Nov AM	0.25	0.75	75.79	2.01	20.61	1.09	9.94	1.00	372.21	10.57	197.28	9.88	84.52	11.28	15127	160.2	< LOD	103.29	13977	246.6	3249.0	147.68	1778.3	143.82	233
16-Nov AM	0.25	1.25	43.58	1.61	21.95	1.08	9.87	1.00	367.47	10.21	211.43	9.86	86.24	11.09	13991	150.1	260.71	55.72	16030	264.5	3124.9	147.81	1688.5	150.95	174
16-Nov AM	0.25	1.75	30.02	1.42	19.86	1.02	7.64	1.00	261.08	8.59	226.59	10.02	96.18	11.16	11703	135.6	512.48	59.53	20881	321.4	3348.2	165.20	2188.8	162.92	122
16-Nov AM	0.75	0.25	43.62	1.61	21.31	1.07	8.18	1.00	364.46	10.19	216.30	9.94	108.27	11.48	13454	148.5	215.89	54.87	15123	260.1	3143.4	148.88	1882.0	146.71	187
16-Nov AM	0.75	0.75	50.55	1.71	20.69	1.07	10.08	1.00	370.86	10.40	180.45	9.38	124.28	11.99	14460	155.6	< LOD	94.70	12807	247.8	3122.3	150.61	1787.4	142.29	164
16-Nov AM	0.75	1.25	35.09	1.54	19.58	1.05	7.32	1.00	267.59	8.99	235.31	10.50	93.12	11.55	11079	137.7	1025.38	71.70	19921	301.6	3082.2	152.44	1837.7	157.06	100
16-Nov AM	0.75	1.75	37.75	1.53	21.71	1.06	9.07	1.00	329.56	9.63	241.31	10.30	86.13	10.85	14464	151.4	< LOD	102.52	18262	284.1	3234.2	153.06	2231.0	146.95	133
16-Nov AM	1.25	0.25	41.51	1.58	20.85	1.06	9.41	1.00	320.39	9.57	206.54	9.75	85.39	11.07	12415	141.6	< LOD	102.11	15926	269.2	3375.3	156.80	1603.1	146.61	137
16-Nov AM	1.25	0.75	50.15	1.70	25.46	1.14	9.15	1.00	307.99	9.45	222.79	10.06	76.81	10.82	12575	144.0	341.63	57.61	17541	275.2	4005.3	163.87	1683.7	144.50	198
16-Nov AM	1.25	1.25	34.45	1.50	21.03	1.06	8.29	1.00	248.63	8.53	180.48	9.31	107.01	11.43	9616	126.0	711.98	64.57	16462	268.3	3119.5	147.60	1764.1	144.17	89
16-Nov AM	1.25	1.75	41.08	1.58	21.40	1.07	9.17	1.00	258.03	8.71	192.13	9.49	71.52	10.77	11838	139.6	538.00	61.57	16651	280.0	3512.9	160.96	1837.5	149.53	105
16-Nov AM	1.75	0.25	41.91	1.58	22.67	1.08	9.19	1.00	234.28	8.24	218.85	9.94	80.85	10.86	9680	125.3	334.64	56.57	18967	290.0	4329.3	172.99	2008.2	150.36	89
16-Nov AM	1.75	0.75	53.95	1.74	24.00	1.12	10.93	1.00	294.21	9.29	185.21	9.38	61.89	10.48	10967	135.3	378.47	58.62	18421	272.2	3708.6	153.80	1509.3	139.03	104
16-Nov AM	1.75	1.25	74.93	1.96	21.56	1.08	17.01	1.00	342.40	9.95	127.60	8.25	72.68	10.71	12922	145.4	< LOD	97.17	9508	212.3	4384.8	164.31	1861.8	145.40	79
16-Nov AM	1.75	1.75	83.11	2.10	19.25	1.07	16.95	1.00	500.09	12.28	118.82	8.23	88.00	11.28	14905	160.3	< LOD	91.39	6845	176.3	3722.6	146.53	1324.8	124.21	139
16-Nov PM	0.25	0.25	43.59	1.60	23.07	1.08	9.98	1.00	363.54	10.05	214.65	9.81	129.52	11.86	14497	152.3	237.64	54.37	16215	282.4	3611.9	165.03	2031.6	153.00	125
16-Nov PM	0.25	0.75	40.85	1.60	23.22	1.11	9.03	1.00	329.57	9.80	193.56	9.61	102.18	11.46	14919	156.6	338.97	57.73	16883	277.5	3383.1	157.02	2049.4	150.40	225
16-Nov PM	0.25	1.25	37.76	1.56	20.54	1.07	8.63	1.00	309.73	9.56	212.08	9.99	88.72	11.32	13035	147.1	378.08	58.97	16929	272.1	3407.7	154.36	2071.5	158.16	160
16-Nov PM	0.25	1.75	52.07	1.74	20.94	1.08	10.56	1.00	442.60	11.37	197.88	9.83	101.49	11.64	16972	169.5	< LOD	98.22	13456	258.8	3179.6	157.15	1784.8	147.51	245
16-Nov PM	0.75	0.25	51.39	1.71	22.55	1.10	10.81	1.00	327.64	9.76	186.91	9.48	71.31	10.68	13062	146.5	376.03	58.44	15152	253.7	3112.1	144.94	1892.3	145.07	160
16-Nov PM	0.75	0.75	47.72	1.70	32.15	1.26	10.28	1.00	299.67	9.46	201.15	9.80	79.51	10.94	11543	139.2	275.91	56.66	25104	319.5	6238.2	198.51	2940.6	164.87	178
16-Nov PM	0.75	1.25	40.69	1.62	26.01	1.17	8.83	1.00	343.03	10.07	228.05	10.32	87.68	11.19	12872	146.9	376.19	58.89	22186	309.8	4027.3	167.63	2568.2	156.90	196
16-Nov PM	0.75	1.75	44.83	1.64	20.54	1.06	9.98	1.00	346.86	10.02	210.10	9.91	90.18	11.25	14774	156.5	< LOD	100.83	14700	257.0	3665.4	159.23	1722.9	145.73	157
16-Nov PM	1.25	0.25	39.18	1.56	23.17	1.09	8.17	1.00	303.26	9.32	201.98	9.67	96.34	11.13	11417	136.6	266.32	55.44	18212	277.6	3107.1	146.22	1899.2	139.37	108
16-Nov PM	1.25	0.75	37.38	1.57	25.40	1.15	9.84	1.00	230.42	8.39	234.87	10.48	82.21	11.28	13049	148.4	625.93	63.76	22716	327.6	4488.7	183.65	2227.2	165.74	138
16-Nov PM	1.25	1.25	46.48	1.64	22.69	1.09	9.81	1.00	263.90	8.78	204.40	9.70	66.07	10.49	11289	136.1	372.74	57.72	17679	277.8	3780.1	160.68	2012.0	147.57	116
16-Nov PM	1.25	1.75	51.35	1.77	23.38	1.15	12.17	1.00	349.91	10.38	220.62	10.51	102.00	12.17	15208	162.7	365.46	60.01	17657	305.2	4297.3	187.80	2115.2	178.76	90
16-Nov PM	1.75	0.25	53.40	1.75	31.58	1.25	11.07	1.00	275.60	9.04	231.64	10.33	74.86	10.81	10430	131.9	692.31	64.83	24877	316.5	5425.3	185.30	2562.5	162.92	460
16-Nov PM	1.75	0.75	58.91	1.80	24.40	1.13	12.07	1.00	281.46	9.15	173.20	9.23	95.28	11.26	11275	137.1	400.99	59.11	17245	265.7	3642.9	153.05	1730.4	137.32	107
16-Nov PM	1.75	1.25	36.53	1.52	20.62	1.05	9.27	1.00	244.93	8.44	156.18	8.76	66.68	10.48	9844	126.4	393.54	58.22	16688	260.6	3309.3	146.36	1739.2	140.02	74
16-Nov PM	1.75	1.75	81.16	2.05	21.44	1.09	16.20	1.00	429.79	11.23	130.19	8.40	67.79	10.68	13516	150.6	< LOD	95.35	8811	200.6	4299.6	162.41	1644.5	139.43	115

Appendix B. Archaeological Data

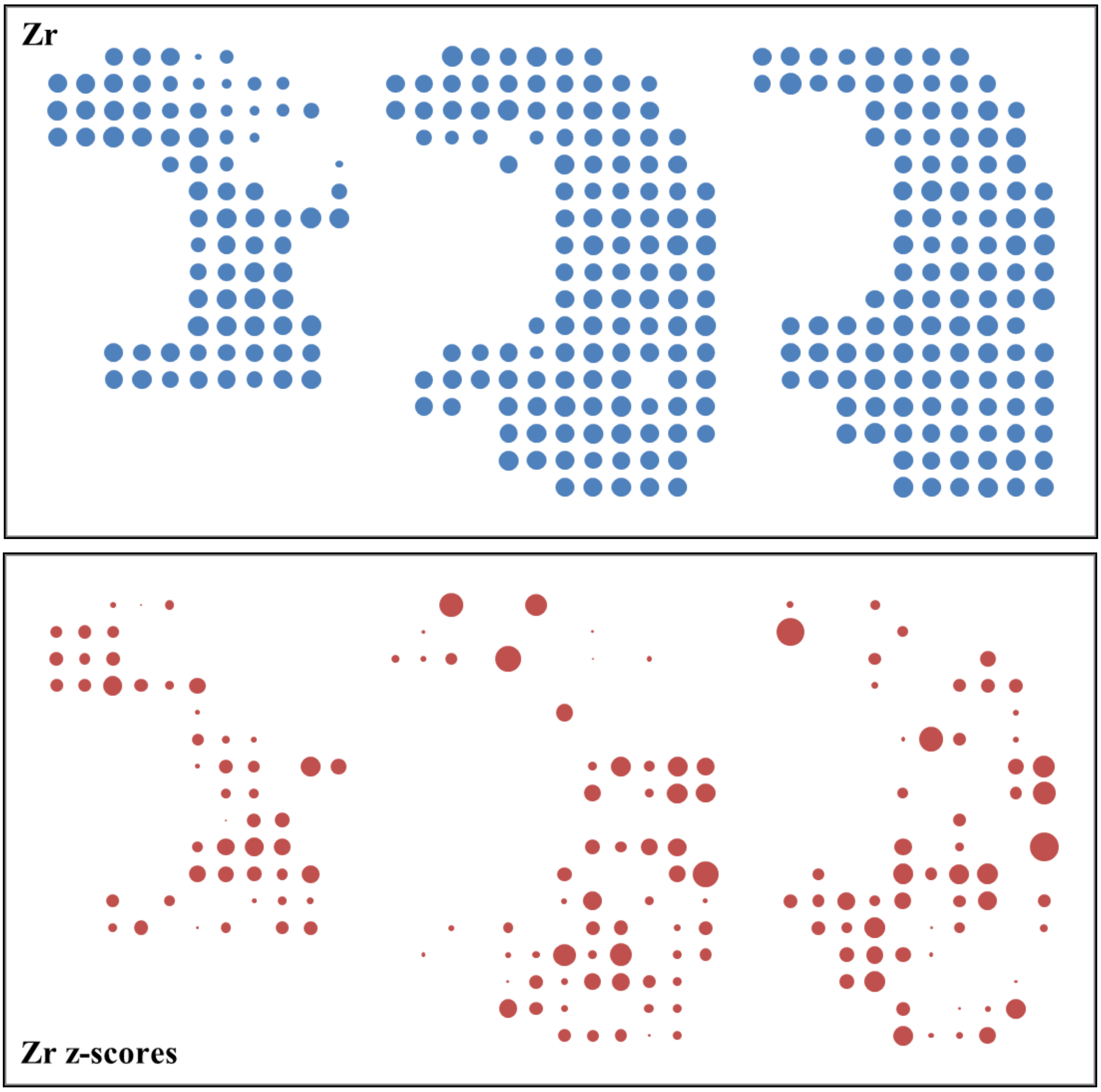


Figure B.1 Bubble plots of (*top*) Zr concentrations (ppm) and (*bottom*) Zr z-scores in the Western House, Trench IV, Maiden Castle. *From left to right*: Floor 6851/Sample 16505; Floor 6852/Sample 16504; and Floor 6853/Sample 16503.

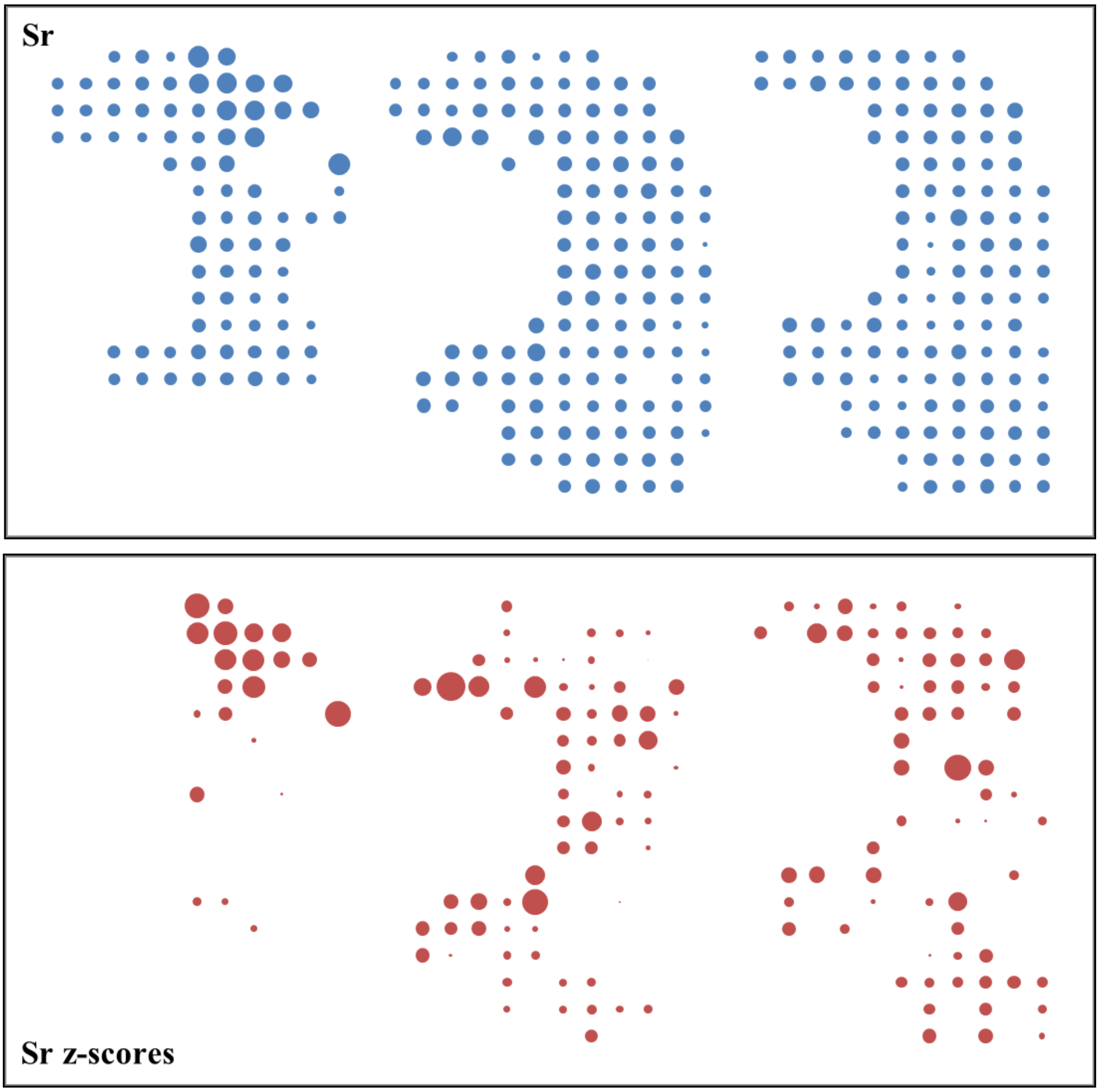


Figure B.2 Bubble plots of (*top*) Sr concentrations (ppm) and (*bottom*) Sr z-scores in the Western House, Trench IV, Maiden Castle. *From left to right*: Floor 6851/Sample 16505; Floor 6852/Sample 16504; and Floor 6853/Sample 16503.

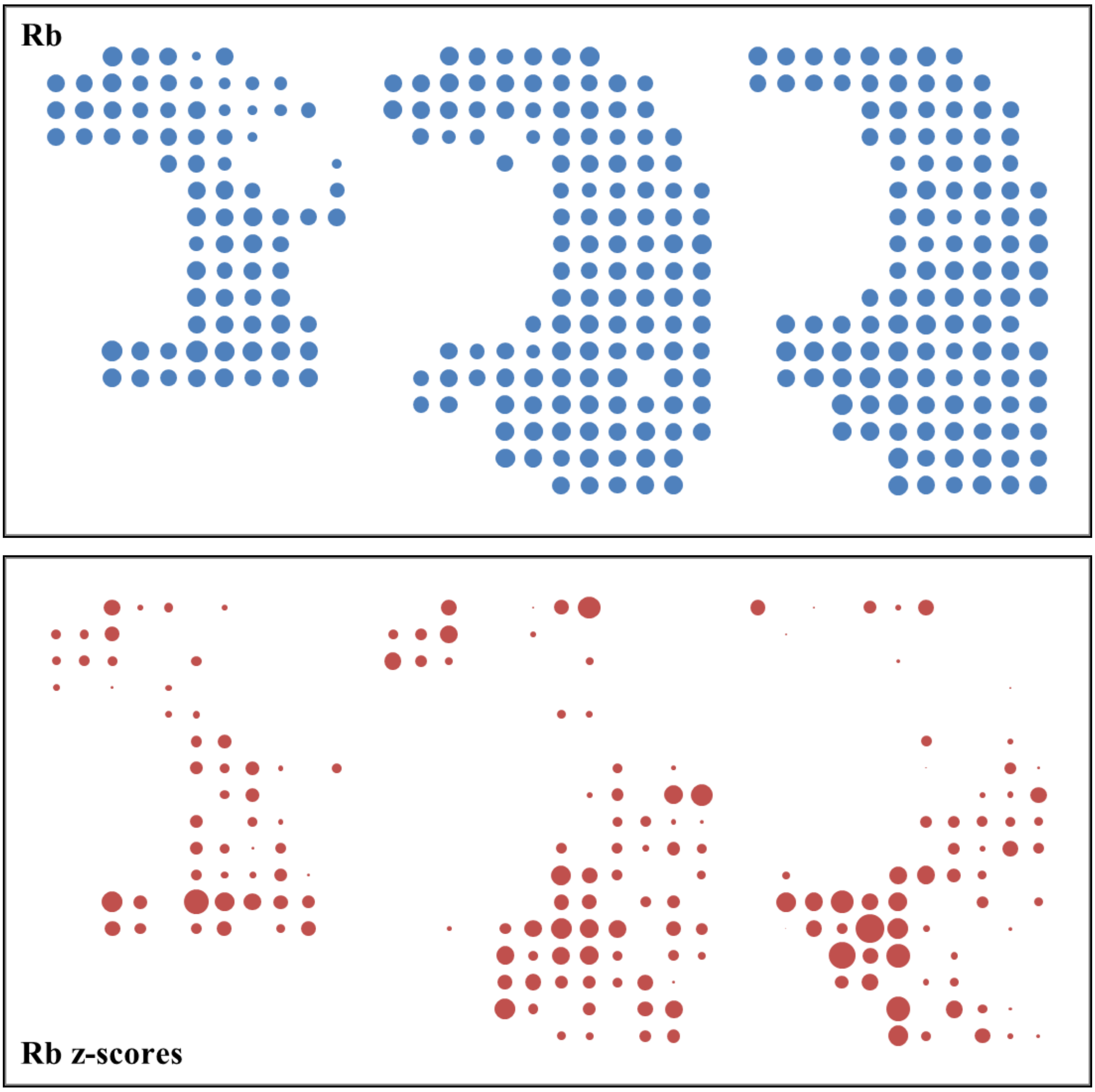


Figure B.3 Bubble plots of (*top*) Rb concentrations (ppm) and (*bottom*) Rb z-scores in the Western House, Trench IV, Maiden Castle. *From left to right*: Floor 6851/Sample 16505; Floor 6852/Sample 16504; and Floor 6853/Sample 16503.

Table B.1 Maiden Castle pXRF and magnetic susceptibility data

Sample	Easting	Northing	Cu	Cu Error	Zn	Zn Error	Pb	Pb Error	Zr	Zr Error	Sr	Sr Error	Rb	Rb Error	Fe	Fe Error	Mn	Mn Error	P	MagSus
16505	558	372.5	223	26.65	276	22.2	23	7.1	273	10.83	225	14.8	53	4.69	25448	358.88	2594	148.63		
16505	558	373	262	28.15	272	22.18	31	7.71	285	11.07	226	14.91	55	4.78	26308	367.03	3030	159.96		
16505	558	373.5	226	27.1	299	23.21	29	7.58	271	10.96	244	15.26	56	4.89	28149	381.45	3200	165.26		
16505	558.5	372.5	214	26.31	256	21.54	28	7.51	277	10.87	185	14.2	50	4.66	26124	363.97	2234	139.45		
16505	558.5	373	178	24.96	294	22.57	20	6.97	266	10.73	234	14.9	57	4.88	25877	360.72	2779	152.93		
16505	558.5	373.5	234	27.28	279	22.59	35	7.97	278	11.04	245	15.24	56	4.85	27989	380.15	3521	172.69		
16505	559	368	169	24.94	296	22.95	27	7.47	253	10.69	243	15.21	63	5.16	26753	372.58	4893	200.62		
16505	559	368.5	192	25.45	288	22.32	24	7.2	276	10.88	256	15.22	74	5.41	22236	335.59	3830	176		
16505	559	372.5	187	25.15	258	21.47	25	7.26	327	11.51	204	14.49	51	4.71	23352	343.73	2104	135.12		
16505	559	373	206	26.69	264	22.25	20	7.07	284	11.24	267	15.72	56	4.93	26909	375.5	2747	155.26		
16505	559	373.5	200	25.95	313	23.5	31	7.64	269	10.9	260	15.4	62	5.1	27851	377.1	3174	163.52		
16505	559	374	166	24.94	347	24.86	39	8.23	240	10.57	215	14.89	65	5.2	32212	410.84	4343	192.18		
16505	559.5	368	194	26.11	252	21.73	25	7.43	287	11.23	257	15.49	58	4.95	26956	374.24	2824	156.47		
16505	559.5	368.5	287	28.87	272	21.86	23	7.17	223	10.24	297	15.82	60	4.95	20601	322.87	3030	157.88		
16505	559.5	372.5	178	24.36	204	19.15	16	6.51	277	10.62	175	13.78	46	4.34	19265	307.63	1638	118.61		
16505	559.5	373	178	24.95	228	20.36	21	6.99	223	10.26	287	15.74	44	4.39	18329	305.95	2378	141.78		
16505	559.5	373.5	168	25.25	238	21.21	24	7.26	229	10.56	305	16.31	43	4.46	19751	323.26	2276	142.2		
16505	559.5	374	181	25.47	245	21.33	29	7.51	233	10.53	290	15.98	52	4.81	20443	326.91	2362	143.71		
16505	560	368	178	24.62	246	20.56	20	6.8	220	10.08	299	15.72	50	4.5	17500	294.91	2159	133.63		
16505	560	368.5	164	24.35	227	20.23	20	6.94	263	10.7	232	14.92	49	4.57	19376	314.02	2445	143.49		
16505	560	372	214	27.05	290	23.14	26	7.47	206	10.28	311	16.42	53	4.85	29431	393.48	3244	168.12		
16505	560	372.5	166	24.74	258	21.55	23	7.2	252	10.71	279	15.72	53	4.71	23466	346.35	2015	133.14		
16505	560	373	186	25.71	203	19.71	22	7.13	206	10.1	298	16.02	44	4.5	19123	313.89	1373	112.92		
16505	560	373.5	184	25.6	251	21.39	26	7.29	184	9.81	316	16.27	49	4.66	19650	318.89	2308	141.09		
16505	560	374	183	24.64	248	20.79	24	7.13	255	10.36	145	13.37	55	4.75	23471	340.75	2209	136.71		
16505	560.5	368	206	26.3	268	21.94	16	6.77	235	10.52	321	16.3	56	4.83	20969	328.39	2719	151.83		
16505	560.5	368.5	195	25.52	279	21.86	16	6.67	210	10.11	379	16.85	83	5.63	17180	294.06	2878	152.76		
16505	560.5	369	199	25.99	257	21.6	23	7.13	307	11.49	310	16.2	56	4.91	19841	320.73	2777	153.57		
16505	560.5	369.5	215	26.32	280	22.25	23	7.03	262	10.74	263	15.37	59	4.98	20931	326.82	3048	159.11		
16505	560.5	370	206	26.02	279	21.98	22	7.06	219	10.19	309	16	59	5	20930	325.11	2801	152.46		
16505	560.5	370.5	192	26.14	210	19.91	7	9.05	173	10	484	18.64	38	4.32	10724	239.79	1521	116.81		
16505	560.5	371	213	26.09	282	21.99	26	7.24	239	10.39	311	15.92	60	4.87	18082	301.52	3122	158.72		
16505	560.5	371.5	177	24.68	273	21.74	24	7.14	267	10.64	199	14.3	57	4.84	21530	328.34	2400	141.76		
16505	560.5	372	202	27.08	563	30.94	33	8.03	238	10.9	361	17.28	54	4.91	19640	327.12	3627	177.46		

Table B.1 Maiden Castle pXRF and magnetic susceptibility data

Sample	Easting	Northing	Cu	Cu Error	Zn	Zn Error	Pb	Pb Error	Zr	Zr Error	Sr	Sr Error	Rb	Rb Error	Fe	Fe Error	Mn	Mn Error	P	MagSus
16505	560.5	372.5	180	25.69	261	22.13	29	7.66	302	11.52	260	15.68	46	4.63	29561	393.8	2248	142.89		
16505	560.5	373	209	27.38	420	27.35	47	8.89	208	10.39	301	16.43	56	4.98	32320	416.84	4149	190.49		
16505	560.5	373.5	186	26.92	141	17.75	16	6.85	106	9.5	641	21.08	29	3.95	9011	226.77	977	99.16		
16505	560.5	374	186	27.82	104	16.04	10	6.57	31	8.55	738	22.51	14	3.51	6122	191.75	709	88.05		
16505	561	368	207	26.32	307	23.22	26	7.32	260	10.84	293	15.93	62	5.08	21187	330.67	2859	155.45		
16505	561	368.5	212	26.02	292	22.35	20	6.91	226	10.32	357	16.57	71	5.32	18369	303.52	2238	136.62		
16505	561	369	191	25.4	263	21.66	27	7.31	298	11.1	198	14.38	53	4.75	21600	331.45	2844	153.95		
16505	561	369.5	149	23.85	245	21.13	21	7.06	309	11.44	285	15.75	55	4.8	25900	363.21	3195	163.6		
16505	561	370	209	26.09	242	20.76	19	6.75	233	10.33	282	15.6	47	4.55	17004	293.79	2435	142.28		
16505	561	370.5	197	25.88	283	22.33	22	7.08	260	10.83	307	16.08	55	4.8	19359	315.25	2491	145.24		
16505	561	371	182	25.14	290	22.38	22	7.03	281	10.98	268	15.43	56	4.83	19161	312.15	2744	150.93		
16505	561	371.5	205	26.17	305	23.02	27	7.43	248	10.57	262	15.38	60	4.95	21517	331.3	2740	152		
16505	561	372	206	27.22	231	21.05	12	6.55	164	9.96	450	18.47	34	4.18	12780	264.32	1478	117.37		
16505	561	372.5	192	26.12	222	20.48	22	7.13	163	9.83	475	18.49	44	4.46	14598	277.43	1714	123.84		
16505	561	373	185	26.59	144	17.44	7	9.35	108	9.41	622	20.63	25	3.84	8279	215.09	1046	101.08		
16505	561	373.5	220	28.77	133	17.42	12	6.66	68	9.08	698	21.96	23	3.8	7194	205.61	706	87.83		
16505	561	374	167	25.54	268	22.26	30	7.79	151	9.77	502	18.99	53	4.79	18235	310.61	1358	113.59		
16505	561.5	368	177	25.64	253	21.53	14	6.59	202	10.23	353	16.95	49	4.66	16621	296.19	1923	130.87		
16505	561.5	368.5	207	25.81	305	22.67	20	6.86	239	10.35	298	15.68	67	5.14	18560	303.7	2484	142.42		
16505	561.5	369	166	24.45	214	19.92	22	7.04	292	11.09	237	14.99	53	4.8	22624	338.73	2389	142.55		
16505	561.5	369.5	157	24.13	223	20.23	22	7.12	321	11.45	186	14.28	51	4.66	22718	340.92	2360	142.39		
16505	561.5	370	226	26.84	307	23.05	23	7.21	284	11.05	272	15.51	56	4.9	19885	318.34	2583	147.3		
16505	561.5	370.5	186	25.06	307	22.76	12	6.23	255	10.51	260	15.14	61	4.93	18683	305.33	2569	145.06		
16505	561.5	371	188	25.36	313	23.01	19	6.79	271	10.85	307	15.9	61	4.98	18528	305.13	2386	140.9		
16505	561.5	371.5	183	25.19	243	20.83	22	6.94	242	10.54	339	16.4	44	4.45	17799	300.44	2715	149.57		
16505	561.5	372.5	173	26.82	149	18.11	7	9.47	83	9.2	663	21.41	19	3.57	6684	198.45	898	95.81		
16505	561.5	373	197	27.94	135	17.33	7	9.43	68	8.96	644	21.3	18	3.53	6543	196.23	669	86.07		
16505	561.5	373.5	192	26.58	191	19.26	14	6.61	145	9.78	562	19.73	33	4.13	13019	263.96	1523	117.75		
16505	562	368	169	24.72	290	22.5	23	7.2	271	10.91	281	15.67	55	4.87	21461	330.84	2741	151.86		
16505	562	368.5	216	26.53	287	22.33	27	7.41	250	10.6	306	15.94	61	4.98	21079	325.97	2642	148.26		
16505	562	369	163	24.23	237	20.73	19	6.92	266	10.68	186	14.19	60	4.94	22254	336.44	2901	155.67		
16505	562	369.5	191	25.6	256	21.5	21	7.08	308	11.29	180	14.17	57	4.85	23481	347.08	2743	152.78		
16505	562	370	172	24.57	203	19.53	21	7	285	10.92	176	14.02	52	4.67	24060	348.88	2388	142.77		
16505	562	370.5	186	26.13	201	20.1	19	7	230	10.69	331	16.8	44	4.56	21496	338.69	1809	129.47		

Table B.1 Maiden Castle pXRF and magnetic susceptibility data

Sample	Easting	Northing	Cu	Cu Error	Zn	Zn Error	Pb	Pb Error	Zr	Zr Error	Sr	Sr Error	Rb	Rb Error	Fe	Fe Error	Mn	Mn Error	P	MagSus
16505	562	371	167	24.22	287	22.11	22	6.95	231	10.12	194	14.21	52	4.67	19002	308.77	2322	139.22		
16505	562	373	157	25.02	192	19.32	11	6.37	130	9.47	519	19.19	26	3.79	9051	222.41	893	93.9		
16505	562	373.5	174	26.2	174	18.71	12	6.55	128	9.61	561	19.91	31	4.08	10201	237.58	1484	117.16		
16505	562.5	368	221	26.43	277	22.07	27	7.28	282	10.81	156	13.66	62	4.98	25966	361.24	2502	145.73		
16505	562.5	368.5	172	24.95	232	20.69	34	7.84	245	10.63	285	15.83	59	4.89	20408	325.02	2861	155.45		
16505	562.5	369	158	24.01	230	20.44	24	7.21	313	11.23	136	13.37	51	4.71	24111	349.56	2304	140.76		
16505	562.5	371	179	25.44	274	22.52	34	7.97	334	11.87	245	15.36	49	4.74	32048	409.16	3759	179.55		
16505	562.5	373	164	25.81	214	20.58	23	7.31	196	10.51	474	18.88	40	4.45	12749	265.55	1463	117.48		
16505	563	371	174	25.27	248	21.58	24	7.39	300	11.49	278	15.91	56	4.9	28792	388.23	2694	154.37		
16505	563	371.5	169	24.61	242	20.81	28	7.46	198	9.71	178	14.1	38	4.14	15543	283.08	1836	126.67		
16505	563	372	162	26.53	141	17.59	13	6.68	39	8.7	783	22.77	18	3.59	6250	192.02	897	95.76		
16504	558	373	191	25.98	322	23.97	24	7.32	263	10.92	275	15.75	63	5.09	26710	372.09	2711	153.55	7250	280
16504	558	373.5	165	24.65	295	22.87	28	7.49	255	10.63	212	14.71	57	4.89	26201	366.35	2680	151.58	5000	142
16504	558.5	367.5	204	26.21	261	21.53	28	7.52	259	10.91	358	16.83	46	4.6	19019	312.53	2214	137.86	6301	290
16504	558.5	368	223	27.06	252	21.29	21	7.15	245	10.75	361	16.91	46	4.49	17015	297.14	2457	144.33	6735	238
16504	558.5	372.5	192	26.3	229	20.89	22	7.29	204	10.38	398	17.64	50	4.71	19949	324.97	2188	139.61	5654	165
16504	558.5	373	212	26.09	281	21.99	22	7.05	260	10.62	269	15.31	58	4.79	22513	334.26	2363	140.22	7743	315
16504	558.5	373.5	199	25.78	311	23.08	28	7.39	258	10.6	244	15	58	4.96	23380	342.37	2707	150.07	6935	394
16504	559	367.5	174	24.99	246	20.98	26	7.27	248	10.57	288	15.72	54	4.72	18404	305.97	2392	141.93	6103	251
16504	559	368	173	26.61	281	23.53	26	7.77	260	11.5	342	17.52	55	5.06	18456	325.38	2196	144.96	7147	265
16504	559	368.5	206	26.22	294	22.6	20	6.94	236	10.5	358	16.68	53	4.74	19096	311.1	2518	144.7	7390	256
16504	559	372.5	189	26.27	155	17.9	12	6.44	151	9.87	575	19.84	34	4.19	11270	246.38	1267	108.57	5118	40
16504	559	373	238	26.79	338	23.61	21	6.92	275	10.68	246	14.83	56	4.79	23297	337.19	2772	149.69	8176	324
16504	559	373.5	205	26.02	302	22.76	26	7.23	247	10.43	256	15.12	63	5.05	22578	335.38	2736	150.16	8103	332
16504	559	374	175	24.89	264	21.82	38	8.09	326	11.5	184	14.19	61	5.05	27416	373.74	3214	164.29	4074	75
16504	559.5	368	183	25.55	270	21.88	15	6.54	256	10.84	369	16.93	46	4.53	17300	298.27	2389	142.14	7250	279
16504	559.5	368.5	218	26.67	259	21.43	15	6.61	228	10.46	380	16.99	43	4.43	17964	301.9	2172	135.74	7154	234
16504	559.5	372.5	182	25.73	186	18.9	24	7.24	164	9.74	435	17.95	42	4.35	13659	267.63	1420	113.55	6059	127
16504	559.5	373	171	25.43	284	22.64	30	7.73	252	10.9	337	16.7	51	4.76	21087	332.32	2448	146.19	5868	265
16504	559.5	373.5	180	24.75	263	21.39	24	7.11	237	10.26	242	14.9	50	4.58	21024	323.28	2457	142.6	6250	368
16504	559.5	374	165	24.27	263	21.53	26	7.35	253	10.53	214	14.59	53	4.77	21657	330.71	2581	147.03	5162	102
16504	560	366.5	195	25.8	288	22.56	25	7.26	299	11.33	301	16.01	66	5.16	20467	324.25	2573	147.96	6199	307
16504	560	367	210	26.44	272	22.09	26	7.4	257	10.83	315	16.25	60	5.01	19797	319.45	2343	141.79	6625	273
16504	560	367.5	212	26.24	282	22.14	32	7.66	260	10.73	309	15.94	64	5.09	20993	324.55	2538	145.42	7301	335

Table B.1 Maiden Castle pXRF and magnetic susceptibility data

Sample	Easting	Northing	Cu	Cu Error	Zn	Zn Error	Pb	Pb Error	Zr	Zr Error	Sr	Sr Error	Rb	Rb Error	Fe	Fe Error	Mn	Mn Error	P	MagSus
16504	560	368	214	26.34	273	21.97	17	6.71	269	10.86	298	15.84	58	4.89	22025	333.25	2556	146.62	6750	327
16504	560	368.5	195	25.57	289	22.28	24	7.18	255	10.67	307	15.94	52	4.67	18639	306.94	2689	148.98	7007	264
16504	560	372	203	26.23	223	20.28	20	7	253	10.83	344	16.68	50	4.64	18879	312.25	2129	135.93	5676	113
16504	560	373	194	26.19	279	22.65	25	7.38	336	11.92	296	16.1	52	4.82	23015	347.88	3714	176.97	5691	356
16504	560	373.5	182	25.08	220	20.05	16	6.68	253	10.68	301	15.95	53	4.71	17789	301.27	2073	133.25	5897	210
16504	560	374	187	25.49	241	21.06	21	7.03	222	10.4	328	16.47	48	4.66	19926	321.85	2964	158.24	5176	163
16504	560.5	366.5	173	24.55	267	21.41	20	6.9	278	10.79	235	14.77	57	4.78	19759	313.04	2336	138.86	7051	323
16504	560.5	367	191	25.91	286	22.67	24	7.36	280	11.15	283	15.86	62	5.13	21698	335.81	2472	146.51	6250	296
16504	560.5	367.5	199	26.02	273	22.14	19	6.83	263	10.85	311	16.11	57	4.9	21498	331.62	2664	150.03	7728	317
16504	560.5	368	204	25.99	268	21.66	32	7.66	248	10.55	296	15.81	63	5.02	19537	314.5	2581	146.57	5676	321
16504	560.5	368.5	190	26.48	157	17.97	36	8.06	137	9.62	518	19.31	34	4.22	8913	222.29	1205	106.61	5566	113
16504	560.5	369	223	27.09	235	20.7	22	7.07	201	10.22	427	17.74	47	4.55	17197	297.54	2006	131.54	6051	179
16504	560.5	372.5	185	26.22	171	18.67	15	6.7	148	9.65	443	18.3	36	4.3	13072	266.39	1673	123.26	4360	62
16504	560.5	373	185	25.36	235	20.57	22	6.99	235	10.39	294	15.8	48	4.52	18345	305.18	2252	137.87	5147	140
16504	560.5	373.5	210	26.02	300	22.63	21	6.94	223	10.13	264	15.28	55	4.8	21044	325.29	3222	161.71	7169	297
16504	560.5	374	162	23.91	256	21.26	29	7.54	314	11.16	118	12.98	54	4.71	26132	361.45	2250	138.92	2691	40
16504	561	366	172	24.76	290	22.47	20	6.83	274	10.87	259	15.28	57	4.89	23375	343.29	2602	147.77	6287	295
16504	561	366.5	195	25.48	266	21.39	19	6.8	263	10.71	305	15.85	53	4.66	19511	312.51	3014	156.29	5941	279
16504	561	367	182	25.52	258	21.71	22	7.14	262	10.92	307	16.17	59	4.92	21813	336.01	2607	149.69	5949	298
16504	561	367.5	166	24.55	250	21.25	23	7.16	317	11.39	198	14.42	63	5.11	23872	348.39	2205	138.41	5676	21
16504	561	368	176	24.89	267	21.61	25	7.36	248	10.5	239	14.99	66	5.18	22033	333.62	2585	147.39	5978	323
16504	561	368.5	195	26.06	285	22.65	28	7.63	260	10.81	225	14.98	61	5.04	22121	339.35	2419	145.37	5603	305
16504	561	369	214	26.32	290	22.44	25	7.21	281	10.97	271	15.45	65	5.1	20507	321.69	2185	136.19	7096	300
16504	561	369.5	211	26.22	281	22.14	22	7.08	247	10.65	347	16.55	57	4.8	19465	313.94	2210	136.76	9301	375
16504	561	370	193	25.77	270	22.04	19	6.92	246	10.75	337	16.6	53	4.8	19508	318.1	2403	143.79	6603	228
16504	561	370.5	180	25.15	251	21.08	23	7.12	244	10.59	324	16.26	47	4.59	17048	295.21	2544	145.64	5721	213
16504	561	371	176	25.71	254	21.68	18	7	248	10.91	367	17.17	49	4.74	18740	315.17	2717	153.44	5904	203
16504	561	371.5	183	25.41	198	19.39	24	7.13	243	10.62	335	16.47	45	4.45	16108	288.47	2122	134.84	5176	142
16504	561	372	197	26.1	266	21.93	33	7.86	294	11.43	355	16.86	56	4.88	20541	326.19	2353	142.76	4743	98
16504	561	372.5	194	25.62	265	21.65	24	7.17	225	10.31	309	16.04	54	4.74	18922	310.42	2277	139.07	4478	119
16504	561	373	183	25.48	249	21.39	23	7.26	235	10.51	287	15.87	48	4.64	20822	329.09	3198	164.07	4765	257
16504	561	373.5	170	24.82	259	21.49	21	6.94	234	10.31	234	14.94	50	4.65	21618	331.75	2975	157.29	4890	242
16504	561	374	175	24.92	305	23.23	36	8.06	236	10.39	210	14.64	60	4.99	28146	379.88	4009	182.37	3838	83
16504	561.5	366	185	25.32	295	22.46	24	7.13	274	10.96	338	16.38	56	4.78	19834	316.08	2600	146.96	5890	254

Table B.1 Maiden Castle pXRF and magnetic susceptibility data

Sample	Easting	Northing	Cu	Cu Error	Zn	Zn Error	Pb	Pb Error	Zr	Zr Error	Sr	Sr Error	Rb	Rb Error	Fe	Fe Error	Mn	Mn Error	P	MagSus
16504	561.5	366.5	205	25.79	257	21.11	17	6.62	234	10.33	320	16.02	59	4.82	18373	302.79	2528	144.03	5735	253
16504	561.5	367	170	25.24	289	22.67	26	7.44	293	11.36	315	16.34	59	5.01	20850	329.73	2790	154.51	5662	233
16504	561.5	367.5	190	25.26	277	21.98	25	7.28	266	10.72	235	14.9	65	5.08	23196	341.41	2678	149.46	5132	227
16504	561.5	368	201	26.26	290	22.84	29	7.58	280	11.11	259	15.51	65	5.19	23432	348.86	2727	153.29	5971	179
16504	561.5	368.5	174	25.04	300	23.02	27	7.45	299	11.26	238	15.1	60	4.98	23042	343.97	2558	147.98	5640	307
16504	561.5	369	158	24.34	284	22.27	24	7.21	255	10.66	256	15.29	61	5.04	21796	332.84	2533	146.17	6515	305
16504	561.5	369.5	202	25.97	264	21.55	24	7.25	285	11.13	347	16.54	54	4.82	18818	308.7	2268	138.37	6915	261
16504	561.5	370	180	25.49	233	20.64	21	7.1	238	10.76	419	17.71	51	4.71	15836	287.18	1943	130.26	5301	71
16504	561.5	370.5	203	26.31	277	22.32	30	7.65	290	11.26	275	15.75	55	4.91	20404	326.71	3233	165.13	5500	226
16504	561.5	371	180	25.32	279	22.15	16	6.76	265	10.88	303	16.01	52	4.73	20334	322.35	2407	143.3	5463	213
16504	561.5	371.5	199	25.65	222	19.98	15	6.38	206	9.99	320	16.09	40	4.24	17423	296.41	2490	143.36	6375	198
16504	561.5	372	192	25.8	253	21.29	26	7.36	245	10.65	319	16.27	56	4.82	18845	311.35	2439	143.82	5963	140
16504	561.5	372.5	173	24.75	255	21.26	12	6.36	251	10.62	298	15.85	50	4.68	19160	311.76	2444	143.23	5147	297
16504	561.5	373	167	24.89	265	21.77	25	7.34	256	10.81	304	16.09	56	4.84	20444	324.57	2388	143.18	4904	173
16504	561.5	373.5	163	24.91	298	23	29	7.66	257	10.9	313	16.31	51	4.65	20841	329.83	2781	154.1	5140	243
16504	561.5	374	153	24.86	344	25.04	30	7.8	251	10.91	265	15.83	68	5.31	34496	427.66	3037	165.09	3882	369
16504	562	366	190	25.67	277	22.12	26	7.26	276	10.95	264	15.44	52	4.72	22003	335.13	2712	151.37	5221	224
16504	562	366.5	211	26.45	272	21.97	25	7.32	237	10.5	304	16.03	53	4.79	19577	317.02	2797	153.15	5412	258
16504	562	367	190	25.29	276	21.76	24	7.17	295	11.08	267	15.3	57	4.76	18739	306.48	2448	142.21	5926	311
16504	562	367.5	185	25.36	266	21.73	20	6.99	318	11.47	254	15.29	57	4.88	22125	335.51	2404	143.2	5257	225
16504	562	368	191	25.33	238	20.67	27	7.31	272	10.71	193	14.23	58	4.87	23647	343.99	2322	140.25	5000	194
16504	562	368	204	25.96	265	21.67	27	7.35	282	10.89	214	14.58	63	5.01	23857	346.69	2689	149.91	5515	257
16504	562	368.5	195	25.75	265	21.68	22	7.04	256	10.7	286	15.73	53	4.76	21000	327.12	2756	151.94	6390	303
16504	562	369	199	25.73	264	21.65	32	7.65	248	10.51	247	15.13	58	4.87	20001	318.78	2422	143.01	6544	291
16504	562	369.5	171	24.55	265	21.51	30	7.58	271	10.76	217	14.62	58	4.88	20904	324.72	2509	144.75	5309	228
16504	562	370	199	26.3	277	22.41	18	6.88	219	10.37	306	16.23	57	4.92	21916	337.85	2268	141.24	6728	349
16504	562	370.5	197	26.34	289	22.9	22	7.17	255	10.87	299	16.16	59	4.97	23420	349.73	2506	148.04	5860	272
16504	562	371	189	25.85	268	22.08	27	7.49	305	11.44	253	15.43	57	4.91	19713	321.62	2887	157.11	8949	249
16504	562	371.5	207	26.03	264	21.38	15	6.61	215	10.14	342	16.38	43	4.29	16093	285.19	2482	142.96	7279	433
16504	562	372	203	26.24	262	21.64	22	7.15	237	10.63	382	17.11	54	4.74	18419	307.32	2230	138.3	6787	214
16504	562	372.5	196	25.84	256	21.44	22	7.07	242	10.6	332	16.41	47	4.54	17773	302.32	2426	143.16	5000	248
16504	562	373	190	25.58	263	21.58	21	7.09	233	10.42	279	15.68	51	4.72	19448	315.67	2411	143.26	5206	167
16504	562	373.5	194	26.7	293	23.46	25	7.43	220	10.53	310	16.5	51	4.82	26220	373.81	2509	150.23	5287	240
16504	562.5	366	178	25.01	289	22.37	30	7.68	257	10.7	281	15.63	58	4.91	21338	328.94	2805	152.79	5779	238

Table B.1 Maiden Castle pXRF and magnetic susceptibility data

Sample	Easting	Northing	Cu	Cu Error	Zn	Zn Error	Pb	Pb Error	Zr	Zr Error	Sr	Sr Error	Rb	Rb Error	Fe	Fe Error	Mn	Mn Error	P	MagSus
16504	562.5	366.5	221	27.41	294	23.12	24	7.35	268	11.11	312	16.39	61	5.04	21540	337.21	2774	155.14	5478	295
16504	562.5	367	174	25.15	299	22.96	32	7.77	278	11.03	273	15.62	61	5	23242	345.4	2788	153.82	5257	215
16504	562.5	367.5	182	24.93	227	20.12	20	6.87	223	10.06	226	14.71	52	4.65	19362	311.24	2099	133.17	5544	345
16504	562.5	368.5	189	25.28	283	22.28	20	6.93	266	10.76	240	15.01	58	4.87	20586	323.6	2673	149.55	5515	288
16504	562.5	369	196	25.46	249	20.97	25	7.16	235	10.31	266	15.34	53	4.71	20020	317.2	2305	139.25	5647	256
16504	562.5	369.5	191	26.14	269	22.23	23	7.17	290	11.33	294	16.07	56	4.9	20621	328.65	2156	138.25	6529	325
16504	562.5	370	234	27.66	265	22.2	18	6.88	234	10.6	301	16.19	57	4.94	24970	360.72	2207	140.3	5368	284
16504	562.5	370.5	181	25	237	20.48	27	7.29	266	10.78	305	15.88	49	4.51	18721	306.75	2492	143.49	5581	266
16504	562.5	371	192	25.59	234	20.58	23	7.2	272	10.93	272	15.59	47	4.55	18325	307.01	2475	144.83	5515	241
16504	562.5	371.5	202	25.97	261	21.45	15	6.47	230	10.52	409	17.41	49	4.63	17321	297.04	2113	134.31	7081	258
16504	562.5	372	190	25.41	254	21.06	18	6.73	251	10.68	377	16.84	49	4.59	16427	287.32	2156	133.93	7316	288
16504	562.5	372.5	213	26.52	279	22.23	22	7.07	240	10.56	284	15.8	44	4.43	21265	331.12	2829	154.83	5551	227
16504	562.5	373	173	25.07	255	21.42	23	7.11	260	10.78	284	15.76	51	4.67	19833	319.33	2660	149.8	5103	234
16504	562.5	373.5	169	24.74	260	21.38	18	6.9	197	9.92	293	15.88	46	4.52	18135	305.11	2463	144.04	3169	196
16504	563	366	191	25.36	271	21.89	24	7.22	265	10.73	248	15.13	59	4.94	20276	320.74	2454	143.77	5529	255
16504	563	366.5	194	25.71	292	22.65	21	6.99	265	10.77	247	15.14	63	5.1	21751	332.88	2865	154.69	5515	235
16504	563	367	203	26.02	276	22.02	27	7.38	267	10.8	262	15.38	55	4.82	18950	311.4	2870	154.35	5596	207
16504	563	367.5	190	25.56	251	21.37	29	7.5	266	10.76	227	14.87	57	4.9	22214	337.47	3161	162.32	5272	192
16504	563	368	170	24.64	234	20.59	25	7.18	261	10.61	190	14.25	60	4.93	21118	327.64	2502	145.6	4794	176
16504	563	368.5	207	25.69	245	20.77	20	6.77	249	10.36	200	14.27	59	4.92	21925	330.42	2606	146.71	5059	263
16504	563	369	170	24.06	231	20.15	24	7.08	294	10.77	115	12.8	53	4.67	23563	339.8	2141	133.93	5007	270
16504	563	369.5	218	26.97	293	23.04	25	7.39	297	11.31	249	15.34	59	5.02	26250	368.35	2459	146.73	5096	247
16504	563	370	371	31.46	245	21.07	21	6.97	244	10.45	250	15.14	55	4.8	19854	316.68	1903	128.34	5735	270
16504	563	370.5	225	26.88	298	22.85	26	7.37	308	11.37	271	15.52	64	5.09	21000	327.56	2569	147.52	6779	282
16504	563	371	205	26.51	269	22.17	18	6.88	306	11.52	290	16.04	55	4.85	20831	330.35	2317	142.72	4978	208
16504	563	371.5	179	25.1	240	20.81	18	6.76	233	10.32	245	15.13	46	4.52	18367	306.61	2390	141.96	5022	192
16504	563	372	172	25.32	251	21.39	23	7.27	254	10.84	293	16.05	48	4.68	17493	303.26	2367	143.28	5265	249
16504	563	372.5	193	25.9	235	20.74	21	6.99	219	10.41	373	17.08	52	4.68	16334	291.98	2576	147.76	5515	144
16504	563.5	367	178	24.4	336	23.57	33	7.62	245	10.09	99	12.49	54	4.66	22293	331.82	3304	162.84	4588	79
16504	563.5	367.5	182	25.06	280	22.09	24	7.19	276	10.84	224	14.76	56	4.76	21650	331.06	2913	155.24	4824	77
16504	563.5	368	293	29.29	278	22.5	26	7.4	281	11.03	205	14.64	58	4.96	23717	350.88	3029	160.66	4647	192
16504	563.5	368.5	149	23.09	231	20.06	15	6.45	259	10.28	101	12.53	49	4.5	21473	325.14	2751	149.23	4324	46
16504	563.5	369	163	24.08	209	19.81	30	7.52	338	11.43	74	12.21	57	4.79	29112	382.32	2254	139.9	3434	80
16504	563.5	369.5	201	25.86	221	20.43	23	7.12	245	10.43	201	14.43	57	4.86	23815	347.59	2050	133.62	5096	222

Table B.1 Maiden Castle pXRF and magnetic susceptibility data

Sample	Easting	Northing	Cu	Cu Error	Zn	Zn Error	Pb	Pb Error	Zr	Zr Error	Sr	Sr Error	Rb	Rb Error	Fe	Fe Error	Mn	Mn Error	P	MagSus
16504	563.5	370	229	27.51	264	22.06	17	6.9	249	10.77	281	15.89	55	4.84	21829	337.37	2009	133.77	5463	315
16504	563.5	370.5	152	23.54	199	19.2	29	7.44	303	10.88	43	11.59	67	5.14	28677	377.57	1929	130.03	4103	112
16504	563.5	371	174	25.27	250	21.74	25	7.53	296	11.32	199	14.66	49	4.73	32754	415.04	4774	201.15	3971	73
16504	563.5	371.5	182	25.16	246	20.98	19	6.92	236	10.38	241	15.08	46	4.4	20269	321.29	2063	133.42	4485	148
16503	558.5	373.5	271	33.7	243	21.07	30	7.51	228	10.29	312	16.01	52	4.66	17974	301.24	2036	131.31	6235	232
16503	558.5	374	237	32.5	279	22.22	20	6.96	257	10.58	240	14.94	63	4.99	19651	314.51	2302	138.86	7088	311
16503	559	368	263	34.62	259	22.33	28	7.68	241	10.84	323	16.7	57	4.99	19257	321.8	2013	135.49	4191	273
16503	559	368.5	303	35.2	277	22.64	27	7.57	286	11.26	291	16.02	68	5.25	21376	334.1	2541	148.65	4706	284
16503	559	369	275	34.65	271	22.56	22	7.29	242	10.82	342	16.84	59	5.1	20085	325.96	2363	144.54	5456	341
16503	559	373.5	313	35.96	273	22.29	17	6.9	354	11.98	252	15.31	57	4.87	20188	322.05	2215	138.2	6007	327
16503	559	374	252	33.68	259	21.87	24	7.31	269	11.01	293	16.03	54	4.81	19457	318.48	2304	141.5	6125	331
16503	559.5	368	221	32.26	260	21.84	23	7.11	287	11.07	251	15.21	65	5.13	18485	308.01	2183	136.86	4184	286
16503	559.5	368.5	249	33.35	317	23.69	32	7.74	282	11	220	14.79	67	5.19	21745	334.29	2598	148.84	4522	325
16503	559.5	369	274	34.32	242	21.37	21	7.06	279	11.2	343	16.69	56	4.84	17471	302.24	2408	143.94	5743	274
16503	559.5	373.5	257	34.23	207	20.25	17	6.92	219	10.58	385	17.46	50	4.76	19522	321.25	1869	130.35	4882	239
16503	559.5	374	238	33.55	248	21.88	18	6.94	256	10.89	272	15.82	57	4.92	24957	362.29	2579	150.85	5265	257
16503	560	367	255	32.94	262	21.58	19	6.81	291	10.92	182	14.02	62	5	18572	305.65	2368	140.5	4971	319
16503	560	367.5	244	33.04	299	23.02	30	7.73	290	11.05	184	14.21	77	5.47	23334	345.09	2696	151.27	4897	323
16503	560	368	232	32.94	289	22.73	23	7.24	276	11.06	292	15.92	60	5.03	20303	323.41	2507	146.26	5882	335
16503	560	368.5	258	33.37	275	22.23	21	6.96	302	11.18	211	14.57	71	5.29	21051	326.99	2415	143.25	5235	407
16503	560	369	258	33.11	260	21.56	27	7.33	257	10.48	201	14.29	55	4.74	20601	320.68	2282	138.09	5081	338
16503	560	373.5	270	34.39	228	21.03	19	7.05	233	10.62	339	16.71	48	4.72	17639	304.98	2300	141.56	4831	218
16503	560	374	267	33.83	234	20.92	24	7.1	208	10.11	332	16.4	51	4.75	16311	289.47	1870	127.26	4926	127
16503	560.5	367	232	32.69	279	22.42	27	7.37	317	11.46	248	15.17	65	5.16	22431	338.06	2752	152.15	6140	312
16503	560.5	367.5	214	31.58	272	21.92	31	7.57	300	11.06	191	14.18	64	5.08	21374	327.39	2467	143.56	4882	320
16503	560.5	368	242	32.68	309	23.18	26	7.39	313	11.18	146	13.45	80	5.56	24176	348.34	2758	151.5	4941	371
16503	560.5	368.5	253	33.63	343	24.56	31	7.76	279	11.1	271	15.66	65	5.2	24164	354.19	3783	177.71	5588	314
16503	560.5	369	264	33.84	229	20.82	22	7.28	242	10.72	338	16.63	55	4.84	16060	289.59	1915	129.7	4787	364
16503	560.5	369.5	265	33.86	261	21.81	24	7.25	247	10.68	313	16.24	54	4.74	17833	303.96	2391	143	6044	283
16503	560.5	372.5	238	33.07	247	21.47	23	7.17	269	10.99	306	16.15	53	4.79	18488	309.83	2266	140	4853	238
16503	560.5	373	413	36.02	270	22.58	31	7.8	281	11.27	311	16.37	56	4.95	22107	340.86	2342	143.93	5074	210
16503	560.5	373.5	237	33.15	277	22.43	24	7.26	259	10.82	295	15.95	54	4.83	22890	342.68	2608	149.46	5103	268
16503	560.5	374	270	34.28	261	22.08	25	7.43	275	11.07	276	15.74	62	5.1	19986	322.72	2365	143.13	5228	206
16503	561	366	247	33.27	298	23.2	33	7.82	309	11.26	163	13.88	68	5.27	24846	356.82	2779	153.79	5000	379

Table B.1 Maiden Castle pXRF and magnetic susceptibility data

Sample	Easting	Northing	Cu	Cu Error	Zn	Zn Error	Pb	Pb Error	Zr	Zr Error	Sr	Sr Error	Rb	Rb Error	Fe	Fe Error	Mn	Mn Error	P	MagSus
16503	561	366.5	225	32.2	282	22.36	25	7.35	285	10.91	174	13.98	73	5.35	23304	343.3	2636	148.76	5228	389
16503	561	367	228	33.19	279	22.8	27	7.52	249	10.81	302	16.23	54	4.85	23314	349.54	2612	151.02	5882	276
16503	561	367.5	218	32.18	328	24.03	39	8.18	291	10.97	129	13.3	73	5.38	25208	359.51	2841	155.6	4735	365
16503	561	368	244	32.15	260	21.28	27	7.23	251	10.22	144	13.23	69	5.12	21976	327.94	2601	145.15	5353	364
16503	561	368.5	233	33.05	290	23.07	27	7.52	296	11.32	238	15.2	67	5.2	24814	359	2477	147.23	4985	351
16503	561	369	247	33.49	287	23	29	7.65	312	11.45	205	14.65	66	5.19	26906	373.15	2781	155.27	5221	253
16503	561	369.5	229	32.15	269	21.91	21	6.98	298	10.94	149	13.46	56	4.75	23953	345.42	2580	146.57	5088	240
16503	561	370	241	33.01	246	21.3	24	7.25	236	10.48	298	15.9	49	4.65	21354	329.67	2310	140.69	6147	216
16503	561	370.5	219	32.39	286	22.74	21	7.06	277	11.03	261	15.47	49	4.62	19618	318.67	2526	146.83	6779	292
16503	561	371	247	33.67	258	21.98	28	7.55	233	10.61	338	16.67	50	4.67	19236	317.25	2349	142.9	6676	281
16503	561	371.5	236	33.23	265	22.21	18	6.92	266	11.02	333	16.58	51	4.69	18374	309.96	2396	143.88	6750	235
16503	561	372	232	32.87	209	19.85	18	6.85	249	10.7	326	16.36	39	4.27	16117	288.43	2271	139.05	6088	262
16503	561	372.5	258	33.29	251	21.28	29	7.48	221	10.15	269	15.4	50	4.65	19429	312.96	2168	135.45	5279	239
16503	561	373	230	32.79	277	22.41	26	7.32	248	10.63	271	15.6	57	4.88	20340	323.89	2541	147.2	4654	149
16503	561	373.5	238	33.64	232	21.23	23	7.29	277	11.24	302	16.32	55	4.89	18431	314.36	3074	162.86	4743	206
16503	561	374	250	33.65	213	20.32	20	6.98	249	10.74	291	15.98	58	4.94	19069	315.63	2378	143.72	5772	216
16503	561.5	366	250	32.98	277	22.13	19	6.8	267	10.83	323	16.15	60	4.94	19946	316.77	2432	142.4	5676	315
16503	561.5	366.5	268	33.79	254	21.38	21	7.02	236	10.43	302	15.94	52	4.7	19155	311.9	2526	145.66	5684	259
16503	561.5	367	230	32.3	281	22.13	18	6.86	253	10.55	292	15.64	58	4.83	19572	312.43	2420	141.47	6309	280
16503	561.5	367.5	249	33.05	261	21.59	21	6.95	266	10.75	267	15.39	56	4.84	19303	312.56	2423	142.58	5926	292
16503	561.5	368	249	33.07	239	21	32	7.71	264	10.68	210	14.54	58	4.93	22194	335.28	2743	151.43	5184	240
16503	561.5	368.5	245	32.98	260	21.68	26	7.27	242	10.48	282	15.63	54	4.74	20034	318.9	2503	145.01	5640	303
16503	561.5	369	204	31.61	294	22.96	34	7.86	282	10.85	123	13.16	67	5.16	30211	391.65	2661	151.6	4662	187
16503	561.5	369.5	209	31.88	292	23.08	26	7.37	245	10.36	123	13.16	55	4.82	36055	427.73	3127	163.91	4794	191
16503	561.5	370	235	32.76	283	22.75	28	7.49	241	10.33	132	13.35	61	5	31581	400.84	2043	135.52	4529	153
16503	561.5	370.5	208	30.74	223	19.9	26	7.13	216	9.52	65	11.76	44	4.26	22350	328.48	2596	144.61	4934	118
16503	561.5	371	235	32.72	293	23.02	32	7.78	262	10.67	183	14.17	57	4.9	29282	385.4	2620	150.31	5162	84
16503	561.5	371.5	240	32.99	279	22.32	24	7.36	334	11.7	259	15.38	60	4.95	19599	316.98	2548	146.91	6397	248
16503	561.5	372	261	33.66	238	21.05	20	7	246	10.65	316	16.2	48	4.53	17885	302.91	2045	132.57	6103	215
16503	561.5	372.5	218	32.4	263	22.01	18	6.81	221	10.32	313	16.19	50	4.67	18971	312.99	2312	140.82	5588	239
16503	561.5	373	277	34.18	269	22.11	31	7.62	227	10.4	325	16.33	50	4.63	20667	325.23	2460	144.63	5801	221
16503	561.5	373.5	236	33.08	239	21.21	26	7.38	218	10.32	311	16.26	51	4.66	19094	315.23	2200	138.39	5221	202
16503	561.5	374	260	33.76	273	22.35	33	7.81	243	10.52	227	14.96	64	5.15	22430	340.1	2552	148.21	5206	281
16503	562	366	218	32.13	280	22.33	22	7.01	270	10.84	258	15.3	52	4.72	22257	335.87	2628	148.62	5926	303

Table B.1 Maiden Castle pXRF and magnetic susceptibility data

Sample	Easting	Northing	Cu	Cu Error	Zn	Zn Error	Pb	Pb Error	Zr	Zr Error	Sr	Sr Error	Rb	Rb Error	Fe	Fe Error	Mn	Mn Error	P	MagSus
16503	562	366.5	245	33.23	304	23.27	22	7.18	264	10.78	231	14.97	66	5.17	21805	334.61	2666	150.65	5397	293
16503	562	367	252	33.32	260	21.76	20	6.98	243	10.54	297	15.86	59	4.91	20742	324.53	2330	140.77	5632	236
16503	562	367.5	248	33.15	274	22.08	22	7	234	10.38	284	15.65	59	4.9	19155	311.52	2219	137.2	6618	355
16503	562	368	253	33.52	242	21.21	21	7.1	278	11.11	310	16.18	53	4.78	20273	322.71	2047	133.91	5228	225
16503	562	368.5	246	33.59	255	21.99	37	8.13	281	11.35	373	17.22	53	4.83	21464	335.87	2625	150.92	5647	241
16503	562	369	282	34.12	287	22.69	31	7.66	310	11.3	198	14.41	62	5.05	21667	332.4	2341	141.57	5860	345
16503	562	369.5	257	33.48	288	22.74	25	7.28	272	10.86	254	15.22	61	5.04	22432	337.45	2743	151.82	6463	381
16503	562	370	268	34.08	287	22.79	27	7.51	282	11.12	272	15.64	61	5.01	21040	329.6	2473	145.68	6676	416
16503	562	370.5	257	33.09	257	21.52	30	7.53	236	10.28	240	14.92	51	4.62	21262	326.04	1991	130.42	5941	294
16503	562	371	293	35.16	170	18.74	16	6.87	172	10.06	469	18.62	40	4.46	12124	255.82	1303	110.59	5588	238
16503	562	371.5	247	33.16	315	23.43	25	7.3	283	11.02	253	15.26	55	4.77	20693	324.69	2585	147.57	7735	349
16503	562	372	286	34.4	338	24.22	21	7.01	238	10.51	312	16.12	46	4.51	19337	314.9	3000	157.95	10140	385
16503	562	372.5	264	34.22	263	22.2	17	6.89	283	11.26	318	16.39	51	4.69	17842	306.18	2297	141.17	6603	296
16503	562	373	255	33.22	244	21.05	25	7.21	234	10.38	323	16.15	49	4.55	18413	304.54	2209	136.52	5588	216
16503	562	373.5	251	33.55	261	21.91	23	7.22	239	10.57	300	16.06	55	4.86	20203	323.14	2261	140.07	5140	233
16503	562	374	232	32.78	270	22.1	35	7.94	248	10.62	276	15.63	49	4.62	19552	316.47	2142	135.81	5919	222
16503	562.5	366	244	33.53	293	23.09	32	7.92	297	11.46	328	16.53	64	5.19	22243	340.91	3275	166.7	5816	352
16503	562.5	366.5	246	33.49	260	21.93	30	7.57	268	10.97	310	16.19	59	4.97	20775	327.8	2740	152.64	5537	229
16503	562.5	367	254	33.3	256	21.62	27	7.33	231	10.39	314	16.1	54	4.8	19362	314.18	2666	149.33	5647	213
16503	562.5	367.5	250	33.36	247	21.34	19	6.89	244	10.65	321	16.29	55	4.84	20197	321.75	2277	140.11	5485	299
16503	562.5	368	244	33.12	238	20.92	29	7.54	245	10.51	250	15.22	50	4.68	19159	312.81	2186	136.83	4838	211
16503	562.5	368.5	223	32.33	256	21.63	36	7.88	307	11.21	184	14.17	61	4.97	22090	334.99	2384	142.72	5581	283
16503	562.5	369	245	32.84	280	22.35	29	7.49	315	11.29	182	14.09	59	4.9	21429	329.64	2809	153.1	6029	358
16503	562.5	369.5	243	32.75	250	21.2	23	7.13	237	10.29	229	14.79	58	4.87	19430	312.81	2373	140.94	5824	336
16503	562.5	370	267	34.11	296	23.14	20	7	262	10.84	268	15.56	61	5.02	24210	352.34	2174	138.06	6382	239
16503	562.5	370.5	370	38.5	263	22.18	25	7.34	248	10.69	304	16.07	58	4.92	21064	329.08	2274	139.99	6985	328
16503	562.5	371	277	34.5	224	20.68	27	7.41	233	10.59	334	16.62	46	4.56	16432	293.4	1969	131.39	6037	240
16503	562.5	371.5	257	33.22	258	21.61	28	7.41	248	10.5	250	15.14	57	4.86	20126	319.23	2530	145.61	6103	302
16503	562.5	372	276	34.25	338	24.44	25	7.32	229	10.33	237	15.1	56	4.84	20789	328.36	2893	156.44	6625	190
16503	562.5	372.5	313	35.23	305	23.33	26	7.44	285	11.18	285	15.84	51	4.68	19541	318.02	2633	149.58	6750	295
16503	562.5	373	301	34.55	277	22.47	20	6.96	293	11.25	313	16.16	54	4.81	18408	307.76	2250	138.75	5963	286
16503	562.5	373.5	252	33.08	241	20.88	21	6.92	227	10.25	291	15.71	49	4.58	18081	302.32	2474	143.4	5044	250
16503	563	366	244	33.15	289	22.88	29	7.52	262	11.34	250	15.1	58	4.92	22888	336.13	2632	144.94	5515	317
16503	563	366.5	246	34.5	293	21.51	28	7.16	309	10.99	242	16.36	57	4.77	22148	318.25	2459	145.45	5221	279

Table B.1 Maiden Castle pXRF and magnetic susceptibility data

Sample	Easting	Northing	Cu	Cu Error	Zn	Zn Error	Pb	Pb Error	Zr	Zr Error	Sr	Sr Error	Rb	Rb Error	Fe	Fe Error	Mn	Mn Error	P	MagSus
16503	563	367	279	32.65	246	22.13	21	7.33	264	10.44	317	15.3	52	4.7	19433	315.41	2451	153.09	5522	215
16503	563	367.5	236	32.36	274	22.09	27	6.89	243	10.57	261	15.12	53	4.92	19565	333.38	2824	144.89	5404	217
16503	563	368	216	33.43	265	21.06	18	7.28	244	10.35	236	15.48	57	4.86	21439	328.13	2426	132.25	5191	190
16503	563	368.5	252	33.35	235	21.33	25	7.43	228	10.24	263	15.89	56	4.74	20926	311.15	1985	152.6	5000	141
16503	563	369	250	32.68	248	20.7	27	7.11	219	10.54	293	14.31	53	5.06	18777	309.5	2773	130.31	4787	259
16503	563	369.5	246	35.03	237	22.69	24	7.05	261	10.55	200	15.35	64	4.96	19135	316.33	1993	135.11	5441	300
16503	563	370	331	32.83	286	21.47	21	7.85	245	10.91	259	15.38	60	4.84	19585	311.23	2121	141.82	6029	340
16503	563	370.5	249	32.93	261	22.36	35	7.7	283	11.13	275	15.03	58	4.98	19454	321	2430	149.28	6750	359
16503	563	371	243	33.59	280	22.72	32	7.05	295	10.84	241	15.26	61	4.89	20282	331.45	2661	147.66	6662	405
16503	563	371.5	261	32.83	288	21.91	22	6.93	268	10.97	252	16.3	58	4.65	21452	302.02	2571	138.01	5912	332
16503	563	372	231	33.2	265	21.52	19	7.15	268	11.11	320	15.94	49	4.85	17674	300.53	2225	133.39	5221	214
16503	563	372.5	247	34.11	254	20.86	23	6.9	287	10.42	302	17.36	57	4.66	17711	271.25	2077	129.37	5603	229
16503	563	373	265	32.72	230	21.5	19	6.97	216	10.7	392	15.55	50	4.85	13994	319.54	1919	138.93	5404	183
16503	563.5	366	237	33.03	256	21.42	20	7.19	259	10.63	275	15.74	57	4.69	20135	314.91	2270	152.74	5375	288
16503	563.5	366.5	244	33.51	251	22.2	25	7.7	250	10.56	286	15.98	51	4.71	19368	320.69	2798	147.91	5456	273
16503	563.5	367	256	33.11	272	22.9	31	7.48	241	10.88	300	14.79	53	4.85	20027	342.02	2579	153.39	5971	231
16503	563.5	367.5	197	33.52	258	21.61	27	7.97	260	11.91	156	14.16	53	4.93	24164	362.66	2500	140.1	5221	
16503	563.5	368	239	32.64	291	22.31	28	6.84	271	10.83	216	13.93	56	4.85	22671	332.09	2755	152.35	5000	191
16503	563.5	368.5	241	30.91	283	21.34	20	7.24	283	10.44	174	13.55	59	4.74	21910	346.02	2809	144.47	4838	186
16503	563.5	369																	4221	117
16503	563.5	369.5	258	33.42	250	21.76	36	7.19	360	10.76	181	15.74	60	4.97	25841	336.01	2248	135.11	4596	141
16503	563.5	370	255	33.26	259	22.89	23	7.45	258	11.63	285	15.08	59	5.16	22225	343.85	2111	148.84	5779	389
16503	563.5	370.5	236	32.51	285	20.22	26	7.05	322	11.38	231	14.37	64	4.83	22692	327.93	2549	129.86	6250	455
16503	563.5	371	233	32.57	221	21.49	22	6.86	320	10.41	198	15.13	57	4.5	21322	316.11	1935	157.83	5515	284
16503	563.5	371.5	238	33.74	260	23.02	20	6.8	244	11.17	252	15.24	48	4.72	19817	321.25	3043	194.34	4191	188

Appendix C. Guidelines for *in situ* analysis of metalworking contexts

In situ *geochemical and geophysical analysis of metalworking contexts*

Summary

The *in situ* geochemical and geophysical analysis of areas of potential metalworking practice begins with the identification of metallurgical debris as well as metallurgical architecture (*e.g.*, furnaces, hearths, anvils) in the course of excavation. For those inexperienced with metallurgical practices and associated archaeological material the Historic England guidelines for Archaeometallurgy (Bayley *et al.* 2001) Historical Metallurgy Society (HMS) datasheets (2014) and HMS research framework (Bayley *et al.* 2008) are the ideal resources to aid in the development of field strategies and characterisation of metallurgical finds and features.

When archaeometallurgical materials and/or features are identified as part of habitation contexts (as opposed to simply as accumulations in pits, postholes, and/or ditches), the potential for geochemical and geophysical survey to reveal the spatial organisation of associated practices and processes. In particular, the presence of metallurgical architecture and/or evidence of hammerscale are suggestive of the discovery of a primary locus of production, rather than a secondary site of deposition or abandonment.

Signs of metallurgical production?

Metallurgical architecture

- *Furnaces*
- *Hearths*
- *Pretreatment areas* i.e., *roasting beds, dressing floors*
- *Anvils*

Metallurgical debris

- *Slag* (ferrous or non-ferrous) can vary in size from microscopic hammerscale to macroscale artefacts – *e.g.*, plano-convex slags, runlets, and furnace conglomerate
- *Minerals*
- *Metallurgical Ceramics – e.g.*, crucibles, tuyères, moulds, and vitrified furnace pieces

Conducting the survey

Geochemical survey

Geochemical survey remains under-utilised in archaeology yet holds the potential to provide an added layer of information with significant interpretive value (Oonk et al. 2009). Recent developments in portable XRF technology (Frahm and Doonan 2013) mean that data conventionally derived from expensive, lengthy, and labour-intensive laboarory based analyses can now be generated in the field so that results can inform excavation strategy. The increasing availability of handheld portable XRF (HHpXRF) technology and individuals skilled in their use means that field directors should now routinely consider their use.

Geochemical survey has good potential to highlight differential use of space yet the relationship between chemical enhancement/depletion of archaeological contexts and its relation to site formation processes remains poorly established. Due to the significant enhancement offered by metallurgical processes, associated contexts offer less ambiguous results than many other archaeological contexts (Oonk et al. 2009). Field directors should recognise that metallurgical contexts offer the potential to not only inform site specific interpretations but the wider development of geochemical approaches to the wider benefit of archaeological practice.

Planning the survey

Before committing to a high resolution geochemical survey a series of rapid transect surveys should be undertaken to ascertain the variation across the site and to determine if the anticipated area of activity contrasts with peripheral areas. The results of transects survey should be fairly assessed to determine the potential for higher resolution systematic surveys.

The survey should proceed when contexts of interest are fully exposed, cleaned and only after they have been adequately recorded. The survey time should be estimated from the number of anticipated samples and period of sampling cycle. The estimated survey period should be discussed and agreed with field director so that the survey can proceed with understood constraints. It is possible to undertake *in situ* analysis and *ex situ* sampling alongside normal excavation procedures but such arrangements will need planning with the imposition of some constraints relating to Health and Safety and excavation logistics. Normally, a survey should be conducted using a sampling grid and a systematic sampling method whereby a sample is taken from within each square of the grid (rather than at the nodes of the grid). Initial survey of floor levels within structures should be undertaken at the highest resolution feasible given time constraints and extent of survey area. Ideally, for geochemical surveys by HHpXRF surveys should aim to work at a sampling interval better than 1m and preferably at 0.5m resolution with the HHpXRF†. When available HHpXRFs should be operated in a dedicated Soil Mode with an analysis time of between 25secs (drift detector) and up to 120 secs for PIN detectors used to determine light elements, *e.g.*., Phosphorus (see below). Elements routinely analysed may include Mo, Zr, Pb, Se, As, W, Zn, Cu, Ni, Co, Fe, Mn, Cr, V, Ti, Sr, Rb, U, Th, Hg, Sc, Ca, K, and S. Floor levels not located within structures should be sampled ideally at 1x1m resolution but up to 2x2m is acceptable for rapidly assessing areas larger than 10x10m. Results from the initial HHpXRF survey can be reviewed on the instrument or peripheral device and mapped rapidly to identify anomalies. Where anomalies are noted, the survey resolution should be fairly assessed and repeated where enhanced resolution (*i.e.*, 0.25-0.5m) may improve the interpretive potential to geochemical signatures of practice.

Phosphorous determination

The determination of phosphorus is among the most familiar soil analyses undertaken by archaeologists (Aston 1985). Although phosphorus is not often indicative of metallurgical processes its method of enhancement is better understood that many other elements. It is therefore a common requirement in post-excavation analysis and the means through which most project directors will encounter geochemical analyses. Phosphorus therefore offers the potential to inform archaeometallurgical interpretation as it can be used to indicate ash and similar deposits.

Dependent upon the HHpXRF unit (*i.e.*, PIN or DRIFT detectors, provision of He or vacuum environments) Phosphorus (total P) analysis can be undertaken *in situ*. The determination of P requires extra time which will need to be adequately assessed and the implications agreed with the site director. Additional samples should always be taken for correlation of P determination with other methods (*e.g.*, ICP-OES).

In situ v Ex situ

These guidelines presuppose the availability of a handheld pXRF for use in the field to conduct the geochemical survey of the site. In the absence of such equipment, survey of sites currently under excavation is still possible. Samples should be taken at the highest possible resolution, in order to account for the possible discovery in the field of any particular areas of interest, and later examined *ex situ* in the laboratory. Time implications should again be agreed with site directors. It should be recognised that current HHpXRF instruments are capable of determining an *in situ* analysis in a shorter time than it takes to bag and label a soil sample. If sampling for *ex situ* analysis is to be undertaken, a trowel should be used to scrape previously cleaned contexts so that approximately 15-30g of soil or sediment should be collected from every grid square. These samples should then be dried for at least 12 hours in an oven at 75 ºC, ground into a fine powder, and placed in a sample pot and weighed prior to analysis.

Geophysical survey

Geophysical survey (Jones 2008) utilising a magnetic susceptibility meter and field probe should take place using the same sampling grid and at the same initial and potential follow-up resolutions as the geochemical survey. Not all instrument meters are fitted with dataloggers and data may have to be recorded and entered into suitable software. As with the geochemical data, these data should be fairly assessed to identify magnetic enhancement warranting further scrutiny at a higher resolution.

Sampling area

In cases where archaeometallurgical features and materials are identified within structures it is ideal that geochemical and geophysical surveys continue outside of the structure as well, in order to better establish understand the relationship between the usage of the interior and exterior spaces.

Data display and representation

Bubble charts are recommended for the display of geochemical and magsus geophysical data. This is particularly important for geochemical data as archaeologist have not developed the same level of data literacy as they have in related areas, *e.g.*, magnetometry and resistivity surveys. Bubble plots therefore offer a straightforward and clearly visible method of data visualisation. It is important to recognise that humans respond to relative size of bubbles in terms of area not diameter, it is essential therefore to scale data to relative areas. Interpolation (*e.g.*, kriging) is only advised when the number of samples for a particular area exceeds 100 and after data have already been examined via traditional bubble plots. The images produced via kriging are in many respects easier to comprehend visually but potentially introduce patterns to the data that do not exist in reality.

Contextualising scales of evidence

The results of the geochemical and geophysical surveys cannot in and of themselves answer all questions concerning past use of space within metalworking contexts. Rather these data can only add to the macroscale artefactual and feature evidence recovered during the course of excavation. It is essential then to monitor finds logs and ensure effective communication with field workers as the distribution of finds will determine to a great degree the decision to embark of geochemical surveys. Enhancements noted in survey results need to be understood in relation to other classes of material discovered within the same context. Through the integration of these differing scales of evidence of metallurgical activity we can begin to create a clearer picture of past practice.

†References to modes on the HHpXRF refer to the Niton XL3T, comparable modes are available on other models.

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