Chapter 1.0 Introduction

1.1 General

The collection and the interpretation of geophysical data from metal-working sites for this thesis has been both challenging and rewarding. Metal-working sites by their nature can be in difficult locations to survey, for example in heavily wooded areas or on very steep slopes. Some sites (e.g. Myers Wood, West Yorkshire) contain numerous slag hummocks, which if combined with woodland can make systematic surveying very difficult to perform. The data produced by such surveys can be equally challenging to interpret. The strong geophysical responses produced by iron-working sites for example, can mask more subtle anomalies that can be equally important if a complete interpretation is to be made. In a few instances (e.g. Kyloe Cow Beck, Hagg End, North Yorkshire and Myers Wood, West Yorkshire) excavations have been conducted on geophysical anomalies. The reward is when the excavation confirms the geophysical interpretation.

The geophysical prospecting of archaeological sites, using earth resistance methods, was first conducted in the 1930s (Gaffney and Gater 2003, 14). The application of magnetic techniques came over several decades later with the development of the proton magnetometer (Aitken 1961, 3). Although Aitken recognized that '*iron is the most obvious and powerful cause of magnetic disturbances*' he did not regard it '*of much archaeological importance because association of iron with a feature is a comparatively rare event, even in Iron Age archaeology. It was the strong thermo-remanent magnetism of burnt structures – and particularly pottery kilns – that suggested the application of magnetic surveying to archaeology'* (Aitken 1961, 3). However, if this technique is applicable to identifying a pottery kiln, why should it not be applicable to any other form of high temperature manufacturing processes, for example glass or metal production? However, since the advent of archeo-geophysical prospecting the deliberate prospection of such sites in Britain has been relatively low. Iron production sites, despite being common in the archaeological landscape in some areas of Britain, for example in Northamptonshire (Bellamy *et al*. 2000-01), the North Yorkshire Moors (Hayes 1978), and The Weald (Cleere and Crossley 1995), they have received very little attention from the archaeo-geophysicist. Elsewhere in Britain Crew (1990 and 2002) has reported widely on the application of magnetic susceptibility and magnetometer surveying in Snowdonia to identify iron-smelting furnaces and slag distribution. In Scotland, fluxgate gradiometer surveys (Photos-Jones *et al.* 1998) have been conducted over Scottish iron-working sites. However their interpretation was predominantly based on topographical surveying.

The current research on British metal working sites presented in this thesis, was initiated to demonstrate that the geophysical responses produced by metal smelting sites could be understood and interpreted using the most commonly used archeo-geophysical surveying methods (fluxgate gradiometer, earth resistance, and magnetic susceptibility) by studying the different geophysical responses and the smelting technology that produced them. Ultimately this would allow metal working sites to be reliably interpreted on the geophysical and topographical evidence, and sometimes documentary, without the need for costly excavations.

Initially the research was conducted on iron-working sites, but as this progressed and familiarity and experience were gained in understanding such sites, the research was extended to include lead, copper and tin. Eventually it was possible, particularly for iron and lead working sites, to use the geophysical evidence to comment on the sites' relationship with the archaeological landscape (See Appendix 4).

This research has spawned a series of papers, reports, posters, abstracts and talks and a list of these has been compiled in Appendix 1.

1.2 Background to research

The current research, and the subject of this thesis, commenced after a pilot study was conducted in 1995 (Vernon 1995, Vernon *et al*. 1998a). In the study three iron-working sites were geophysically surveyed in Bilsdale, and Rievaulx, on the western side of the North Yorkshire Moors National Park. In Bilsdale, one of the surveys on a monastic grange site identified a series of linear anomalies and a large area of slag suggesting some degree of permanency to the site. Metallurgical analysis of the slag showed that a simple shaft furnace had produced it, although no furnaces were identified on the survey. In contrast, geophysical surveys on a potential water-powered site identified anomalies consistent with a sophisticated infrastructure. Leats and furnace housing were identified and analysis of the slag confirmed that the site had the potential to switch between several modes of iron production. At Rievaulx a conspicuous dump of furnace bottoms and slag produced by a cast iron refining process was surveyed. The survey delineated the limits of the dump. It was possible from the geophysical surveys to deduce the layouts of the sites, and describe how each site functioned (Vernon *et al*. 1998b). In the current research all three sites were revisited and additional surveys undertaken to, (i) refine the survey resolution, and (ii) extend the surveys building on the experience gained from completing and interpreting the geophysical survey results from other iron smelting sites.

Since 1996 further geophysical surveys have been conducted on iron smelting sites in North, West and South Yorkshire, Rutland, Northamptonshire, Kent and Hampshire. The surveys represent a wide cross-section of iron-working site types varying from simple shaft furnace technology, to the introduction of water-powered techniques through to charcoal-fired blast furnaces and associated forges. The iron ore source varied from a possible bog iron ore, through to siderite ($FeCO_3$) ores mined from the Carboniferous and Jurassic of Yorkshire and the Midlands, and possibly the Wealden Cretaceous. Eventually the research was extended to include lead, copper and tin smelting sites.

Three lead smelting sites have been geophysically surveyed in the Yorkshire Pennines for this current research. The geophysical surveys have embraced sites ranging from a simple bale that employed simple 'bonfire' technology, through to elaborate smelt mills that used ore hearth and reverberatory furnace techniques. In all those examples the smelted ore was galena (PbS).

The relatively scarce distribution of copper ores, predominantly chalcopyrite ($CuFeS_2$), confines copper smelting activity to a few locations in the British Isles. Sites employing simple shaft furnace type technology are unknown, although such a site may have recently been recognized in North Wales (E. Roberts, Great Orme Mines, *pers. comm.*). Two isolated copper smelting sites have been geophysically surveyed, in Staffordshire and North Yorkshire, the former was water-powered and both sites are believed to have employed simple furnace technology.

Economically viable deposits of the tin ore cassiterite (SnO_2) are confined to Devon and Cornwall. Magnetic igneous rocks posed a possible problem for fluxgate gradiometer surveys in these counties. Geophysical surveys were conducted over several tin blowing houses, smelters that utilized simple shaft furnace technology. Such sites are well documented and generally water-powered (Gerrard 2000).

Although the ore types differ, the processes and their related smelting structures and infrastructure are similar in concept and morphology. The wide range of smelting sites that were geophysically surveyed enabled the most important phases of smelting technology to be examined. The systematic geophysical surveying of iron smelting sites in one particular area, Bilsdale and Rievaulx, North Yorkshire, has allowed these sites to be placed in the archeo-technological landscape (See Appendix 4). Whilst iron-smelting sites had received attention by other geophysical researchers in Britain (Crew 1984, 1989, 1990, 1991a, 1997, 2002; Photos-Jones *et al*. 1998) none of those sites were apparently related either spatially or chronologically. Lead smelting sites have had even less attention and only three simple lead smelting sites had been geophysically surveyed prior to the commencement of this research (Willies 1990,1; McDonnell *et al*. 1992; Evans 1993). Hamilton (1998) extended the research further with the geophysical examination of simple lead smelting sites in North Yorkshire. Prior to the current research there were no known geophysical surveys of copper and tin smelting sites in Britain.

1.3 Previous research

Only a very broad outline of previous research will be given at this point. This topic will be covered in detail in the Chapter 3.

The results from the geophysical surveys of a relatively small number of British smelting sites have been published (e.g Crew 1984, 1989, 1990, 1991a, 1997, 2002; Photos-Jones *et al*. 1998), and only a few of these examine the geophysical data in detail. Despite the rewards from such application most geophysical surveys are conducted on an *ad hoc* basis and those surveys when published are often inadequately interpreted. Recent published examples include Challis's (2002, Figure 3) paper that features a grey-scale plot of a fluxgate gradiometer survey of an iron-smelting site merely to show that anomalies have been identified for target excavation. No other relevant detail is offered, for example the survey resolution. Similarly Pleiner's (2000) publication provides extensive coverage of excavated iron-smelting sites throughout Europe, including Britain, but only makes fleeting reference to the use of geophysical methods on such sites.

In continental Europe two smelting regions have been systematically examined. Abrahamsen and fellow researchers (Abrahamsen *et al*. 1998; Abrahamsen 2001; Smekalova 1996; Smekalova and Voss, 2002) have concentrated on the geophysical examination of iron slag-pit technology around the Baltic Sea (north Poland, Germany, Denmark and Sweden). Slag pits represent one phase in iron-smelting technology but are a significant component of the archaeological landscape in areas around the Baltic Sea. The research on these sites has now progressed to examining methods for dating the individual furnaces by mathematical analysis of the geophysical responses (Abrahamsen *et al*. 2002).

In the Vosges area of France systematic geophysical surveying of lead and iron smelting sites has been undertaken with mixed success (Ancel and Fluck 1990, 78; Fluck 2000, 176; Grandemange 1990, 116). Elsewhere in Europe (e.g. Hungary, Austria, Germany) surveys of metal working sites are sometimes conducted to support other archaeological investigations (Gömöri and Wallner 1984; Cech and Walach 1990; Goldenberg 1990).

Although archeo-geophysical prospection is widely used throughout all of Europe there would appear to be very little focused research on for example, establishing site characterization or using the data to position such sites in the landscape either spatially or technologically, and this is one aspect that will be covered in this thesis.

1.4 Research Aims

The research supported by this thesis represents the first attempt to study a variety of British iron, lead, copper and tin smelting sites by their systematic geophysical survey. By understanding the smelting techniques it will be possible to look at the geophysical data and make valid detailed interpretations both of the furnaces and associated infrastructure. In addition, the geophysical examination of slag will be used to show whether it is possible to draw basic conclusions about the technology that produced it. Finally an accurate assessment of the site from the geophysical data will enable it to be positioned in its historical and technological setting, important aspects when considering the influence of the site in the archaeological landscape. This will be achieved by:

(i) Examining in detail the geophysical responses produced by metal-working sites by experimentation and survey with the objective to identify key site features on the surveys and speculate how they functioned, either individually, or as a component of the archaeological landscape.

(ii) To use the geophysical data to determine furnace morphology.

(iii) Assessing the effectiveness of magnetometry (fluxgate gradiometer), earth resistance and magnetic susceptibility techniques for surveying metal-working sites. Those methods most widely used in archaeological prospection in Britain.

(iv) Devising a methodology for surveying metal-working sites and for presenting results.

(v) Measuring the magnetic susceptibility of slag, a major component of a smelting site, to determine if specific ranges of values characterize slag from a specific smelting process and discuss its contribution to responses recorded by magnetometers.

(vi) To comment on the type of metal smelting site that may not yield reliable geophysical data.

1.5 Delineation of the current research

The following topics have been excluded, or identified as being outside the scope, of the current research:

(i) Archaeo-magnetic dating by mathematical analysis of the geophysical response produced by simple iron smelting furnaces is currently being examined by several researchers (Crew *et al*. 2000a**;** Abrahamsen *et al*. 2002). The main point of interface with work presented in this thesis is discussion on the form that the geophysical response, produced by simple furnaces, takes. It requires detailed mathematical analysis of the response and is outside the topics covered by this thesis.

(ii) The time range for the study begins with the earliest known smelting technology through to the early 18th century, the point when coal (primarily in the form of coke) was starting to replace charcoal as the principle fuel source. Where appropriate, comments will be included on later smelting techniques and specific examples included, where it is not possible to include earlier examples.

1.6 Summary of thesis contents

The research is presented in five main chapters that will allow the geophysical responses from smelting sites to be compared with features identified by archaeological excavation and ultimately enables some of the results to be placed in their archaeological setting.

Chapter 2 outlines the principles behind the geophysical techniques and the survey methodology. Data presentation is also described and examines why some data processing methods may be superior to others for presenting this type of data.

Chapter 3 is a historical review of literature about geophysical surveys over smelting sites and includes the types of expected geophysical responses associated with smelting sites described by other researchers.

Chapter 4 provides details of the experimental work conducted over furnaces to duplicate these responses and evaluates what other furnace parameters may be obtained from the results.

Chapter 5 describes the various smelting processes for the production of iron, lead, copper and tin together with the evidence from archaeological excavations to demonstrate known chronological changes in the technology. Interpreted results from geophysical surveys show how the various processes produce different geophysical characteristics, and the different features that may be identified from such surveys.

Chapter 6 examines the magnetic susceptibility of slag. Different ores and smelting processes produce slag with varying magnetic signatures that can be used for their characterisation.

The thesis is published in two volumes. Volume 1 contains the text and the references and Volume 2 contains the supporting figures and appendices.