CHAPTER 12: CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

12.1 Conclusions

The following are the general conclusions of this research, drawing together the underlying themes, aims and objectives stated in Chapter 1; for conclusions specific to each industry or research topic, reference should be made to the appropriate chapter. Although a limited number of sites were examined in this research, conclusions have been drawn which could be applied to all sites within each of the industries investigated; it should be noted that different sites of an industry could be situated on different geologies and the conclusions may have to be modified accordingly.

The identification of the medieval and post-medieval industrial sites of iron smelting, lead smelting, glass production and charcoal production has been improved by better interpretation of geophysical magnetic survey data. By means of comparing the survey data with the results of site excavations and with laboratory analyses of samples from the industrial processes, the main components of these industrial sites can be identified and distinguished with a higher degree of certainty than before.

Laboratory measurements of samples have demonstrated a wide range of magnetic susceptibility values, as expected in the majority of samples but including the unpredicted high susceptibility results from the Myers Wood iron smelting site. The research has shown that there is a range of magnetic anomaly strengths associated with a site which aids the identification of the type of industry being observed, and which, along with other factors such as proximity of industries, geographical location and geological considerations, are also of assistance in discriminating between industries. There is, however, the potential for mis-interpretation of survey data due to similarities

in size, shape and strength of magnetic anomalies. Observations of the Rievaulx experimental iron smelting furnace and the blacksmithing demonstrations show how the "patterns" of magnetic anomalies could be derived which will go some way towards better interpretation of activities on other similar archaeological sites.

In this research, geophysical surveys were undertaken principally using magnetometry (fluxgate gradiometer) but volumetric magnetic susceptibility surveys were also proved useful as a complement to magnetometry, but only in circumstances where ground surface conditions at the various sites surveyed were found to be suitable. Magnetometer surveys, and magnetic susceptibility surveys where appropriate, have recorded and identified the principal components of the sites studied in this research, in particular the spatial extent of the activities related to the particular process, e.g. for iron smelting sites, the ore roasting area, the furnace and the slag deposits. In general, magnetic anomalies associated with the main components of a site were observable in the survey data plots but there were occasions where there was a lack of "contrast" in the data and the anomalies were not clearly defined. Factors which affect the identification of an anomaly are its depth beneath the ground surface, its magnetic strength and the magnetic characteristics of the surrounding soil or heat affected clays.

Interpretation of survey data still relies on good quality data. Higher resolution surveys whilst leading to more "concentrated" data do not necessarily result in more accurately recorded data. For the best data interpretations, higher precision must be accompanied by higher accuracy, which implies a potential lengthier survey time. In practice, as there may be time limitations on a survey there will be a trade-off between precision and accuracy, and lower resolution survey data, at a minimum of 0.25m recording intervals, will have to be accepted. In circumstances such as these, interpretations of the survey

data will be produced which will be based on optimised data recording. As the methodologies employed in this research demand a high degree of precision and a significant amount of data collection and analysis, it is intended for the methods described to be carried out only after general or reconnaissance site surveys have been completed and targeted survey areas identified; to expect high resolution geophysical surveys as described here to be undertaken from the start of investigations into a site would be resource intensive and extremely impractical.

A combination of fractional conversion and heating experiments has proved to be a useful means of identifying the effect of operating temperatures on the magnetic susceptibility of natural clays. The attempt to identify changes in the iron oxide states within the mineralogy of the clay samples at different temperatures by means of XRD analysis was not successful. A methodology was devised whereby a combination of measuring the magnetic susceptibility of samples obtained by a specific method ("linear sampling") from the heat affected surfaces adjacent to an iron smelting furnace and a series of heating experiments on samples of natural clay from the same site allowed temperature/susceptibility profiles to be constructed. From these site-specific profiles an estimate of working surface temperatures could be made; however, there is insufficient data using this methodology to determine furnace operating temperatures and further investigations are required, as discussed in Chapter 7. In this research, this methodology could only be applied to iron smelting sites since there was a lack of reported instances of new glass production sites in the UK, and the magnetometer surveys undertaken in this research showed that lead smelting and charcoal production sites did not sufficiently enhance the magnetic characteristics of their respective working surfaces.

The magnetometer surveys have identified the high value magnetic anomalies of the iron smelting and glass production industries which have the potential for being dated by archaeomagnetic methods, i.e. where there has been sufficient heat from the industrial process to enhance the magnetic properties of the ground to the extent that thermoremanence has been acquired. Surveys of the other two industries investigated, lead smelting and charcoal production, demonstrate that thermoremanence is not acquired and as a consequence, it is extremely unlikely that these two industries can be dated archaeomagnetically. The statistical investigations into the material which would provide the optimum dating samples from an industrial site, by necessity limited to iron smelting sites, demonstrated that archaeomagnetic dates can be obtained from both furnace lining material and the surrounding heat affected clay without prejudice to either material; there was no significant difference between dates derived from lining samples and those from heat affected clay, and no sampling bias is necessary.

12.2 Suggestions for further work

As a consequence of the geophysical surveys undertaken over the industrial sites and of the measurements and analyses of the samples obtained from these sites, suggestions for further work are made. These are listed below in chapter order.

12.2.1 Iron smelting

(a) Undertake fractional conversion and heating analysis of soils and underlying geology to determine the capability of an iron smelting site to acquire magnetic enhancement;

(b) Build and operate an iron smelting furnace, having thermocouples installed within and beneath the structure to measure the operating temperatures, with the objective of examining the effect of the smelting process on the magnetic characteristics of

the ground on which the furnace was constructed and determining the extent of any magnetic enhancement which had occurred. It is recognised that there would be difficulties in obtaining sufficient material (ore, fuel and structure material) and permissions;

(c) Using experimental furnaces, undertake investigations into the reasons for the higher than expected quantities of metallic iron in both iron smelting slags (as found in the samples from Myers Wood) and blast furnace slags (in the samples from Rievaulx and Sowerby Bridge);

(d) Investigate through further geophysical survey and excavation the area to the north of the Kyloe Cow Beck iron smelting furnace: the original 10m grid magnetometer survey plot (Vernon 2004) identified distinct activity which could be the remains of an ore roasting feature or possibly another furnace;

(e) To ensure that roasted ore and similar high susceptibility material, such as slag containing prills of metallic iron, is recovered, an excavation strategy should be prepared detailing the method of retrieval and recording.

12.2.2 Lead smelting

(a) There is sufficient survey and visual evidence to conclude that lead smelting was also taking place in the area of Site 22 on Totley Bole Hill. Further investigation to determine the nature of the anomalies (A) and (B) in Figure 4.42 is recommended. It is possible that the effects of (A) are masking further low level activity similar to anomalies (d) and (E);

(b) Survey and sample another bale site, such as at Windegg No. 1 which has been identified by the author as suitable for further investigation (Murphy and Baldwin (2001) notation WEG1);

(c) Excavate the Dacre lead smelting site as a follow up to the geophysical surveys carried out by Vernon (Vernon *et al*. 1999);

(d) Survey and sample a blackwork oven, an example of which was located on Totley Bole Hill;

(e) Undertake fractional conversion and heating analysis of soils and underlying geology to determine the capability of a bole/bale site to acquire magnetic enhancement;

(f) Build and operate a bole/bale, having thermocouples installed within and beneath the structure to measure the operating temperatures, with the objective of examining the effect of the smelting process on the magnetic characteristics of the ground on which the bole/bale was constructed and determining the extent of any magnetic enhancement which had occurred. It is recognised that the shape and size of the structure would have to be assumed and that there would be difficulties in obtaining sufficient material (ore, fuel and structure material) and all the required permissions.

12.2.3 Glass production

The results of the glass production site investigations are tentative and need to be tested if and when the opportunity arises with the discovery of a new glass production site.

12.2.4 Charcoal production

As the Dalby charcoal kiln experiment was a unique event, it would be prudent to test the results by undertaking another experimental charcoal burn, to eliminate or reduce the effect of personal preferences and to confirm the amount of magnetic enhancement produced by the charcoaling process where different kiln sealing arrangements are used. The following should also be considered if another burn is attempted:

(a) The construction or re-use of a fully compacted clay platform, so that water and liquid effluent can drain away from the kiln without creating a "liquid" insulating layer;

(b) On the assumption that burnt turf would produce negligible ash, the kiln structure should be fully turfed and maintained with turf, in order to minimise the ash layer across the platform;

(c) The thermocouple support arrangements should be discussed with the kiln builder before the build and where possible a support framework or similar which causes minimal disruption to the kiln structure as it slumps should be erected (for example, a series of hollow steel tubes fixed vertically into the platform - each thermocouple would be run underground to one of the tubes and threaded internally to the appropriate height);

(d) More thermocouples or a different arrangement, to record temperatures along more than one transect through the kiln and platform.

12.2.5 Analysis of soils with specific emphasis on the relationship between magnetic susceptibility and temperature

(a) Depending on the extent to which furnace features have survived in the archaeological record, linear sampling of the heat affected working surface along the same axis as the tuyere should be considered, in order to investigate whether the heat from the furnace travelled further into the surrounding clay surface along this axis. If so, then it may be possible to detect the resulting anomaly through magnetometer survey. Conversely, an extended high susceptibility/temperature area might be an indicator of the position of the tuyere;

(b) As a means of determining the thermal conductivity and other appropriate thermal characteristics of natural clay material, hence deriving a better understanding of

susceptibility/temperature profiles, heating experiments should be carried out on one or more fully-instrumented blocks of natural clay; although these experiments would be undertaken on a site specific basis, they would provide a general view of the thermal behaviour of this type of material.

12.2.6 Microscopy

A possible solution for ensuring that discrete areas of high susceptibility material are contained within a section would be to radiograph each high susceptibility sample, to determine where the discrete areas were located within the sample and thus enable appropriate positioning of the section. It is recognised that this procedure could be resource intensive and perhaps only suitable in specific instances. An alternative approach would be to obtain a greater number of thick sections from each high susceptibility sample, analyse each section separately and combine the results.

12.2.7 Formation processes: the first impressions

(a) Further investigations into iron smelting and its effects on magnetic properties are required, subject to appropriate resources; another experimental furnace should be considered but this time built into banking similar to that which has been commonly found on iron smelting sites, such as Kyloe Cow Beck and Hagg End (both in Bilsdale, North Yorkshire) and Ashwicken, Norfolk (Tylecote and Owles 1960);

(b) Greater use of magnetic susceptibility survey methods should be considered, so that changes in the magnetic characteristics in soil layers may be identified as they are removed: this will allow improved recognition of working surfaces, pathways, etc.;

(c) Undertake thorough and methodical sampling and sieving of the soil layers as they are removed, so that the extent of slag dispersal at iron smelting sites and hammerscale and other debris at smithing locations may be better identified.

12.2.8 General

Consideration should be given to conducting magnetic surveys at a resolution greater than 0.25m (5m x 5m grids) on a regular basis, where there is a need to identify specific features of an industrial site in greater detail; a resolution of 10cm is suggested.