CHAPTER 11: COMPARISON OF THE INVESTIGATED INDUSTRIES

11.1 Introduction

In the previous chapters, samples of material from sites associated with iron smelting, lead smelting, glass production and charcoal production were studied on an individual industry basis. Consideration was also given to the geophysical surveys undertaken over specific sites and targeted areas, which identified the magnetic anomalies produced by the main components of these sites. This chapter will bring these individual studies together through a comparison of the each industry's analyses and results in order to provide further means of characterising each industry type; themes evaluated are magnetic susceptibility, magnetic viscosity and site components.

11.2 Magnetic susceptibility

Laboratory measurements and analyses of the magnetic susceptibilities of the natural clays, soils, slags and residues were undertaken to determine the cause and/or composition of the magnetic anomalies detected through geophysical survey. It should be noted that no direct comparison can be made between the magnetic anomalies identified from a magnetometer survey and the magnetic susceptibility of sample material corresponding to these anomalies, due to the variability in depth of the sampled deposits below the magnetometer sensors. (See Chapter 3, section 3.8.2.5 for the discussion regarding the comparison of the Myers Wood slag deposit susceptibilities and the equivalent magnetometer survey data.)

Earlier chapters identified a hierarchy of magnetic susceptibilities of the natural clays, soils, slags and residues at each of the various industrial sites researched. These hierarchies are shown individually in Figures 3.17 (iron smelting), 4.37 and 4.38 (lead smelting), 5.10 and 5.11 (glass production), and as a composite in Figure 11.1. It should be noted that as only an unavoidably limited number of sites were investigated, the number of soil and natural clay samples, representing specific site location geologies, were restricted. A broader range of soil and natural clay samples, reflecting different geologies, would possibly have resulted in a slightly larger range of susceptibilities to that shown.

From Figure 11.1, it can be seen that there is considerable overlap in susceptibilities between several of the material types. In particular, there is similarity in susceptibility in two groups of material: (a) blast furnace slags and lead smelting slags, excluding Penguelan heavy slag, and (b) Penguelan heavy slag and glass fragments. All these samples are morphologically varied but their structures are essentially the same, being based on a non-crystalline glassy phase. Samples of material from known sources, whether lead boles/bales, glass production sites or blast furnaces, can be measured for magnetic susceptibility and compared with the data from this research. However, there may be occasions when samples of unknown type and source, but similar morphology, i.e. having a glassy phase appearance, are encountered “out of context”. Magnetic susceptibility analysis would not necessarily identify these samples as being the by-products of a blast furnace, bole/bale or glass furnace; other investigative techniques, such as X-ray fluorescence or optical/scanning electron microscopy, would be more appropriate.

The magnetic susceptibility measurements of the various samples of slag and residues tabulated in Chapters 3, 4 and 5, coupled with the optical microscopy observations and the SEM quantitative results given in Chapter 9, serve as a primitive database against which samples from known or unknown sources can be compared. The samples of slag and residues analysed in this research are from a restricted number of high temperature industrial sources, due to the time constraints of the research period. Further sample material is required for analysis, in order to strengthen the database.

11.3 Magnetic viscosity

The response of samples when being measured with a Pulse Induction Meter (PIM) usually consists of the viscous magnetic decay but could include the effects of electric (eddy) currents generated by the PIM transmitted field if the samples contain free metallic particles, e.g. prills of iron or lead. The application of a transient magnetic field (as in a PIM) to samples containing free metallic particles causes eddy currents to be generated which decay exponentially with time constants of a few μs; other samples which do not contain free metal display magnetic viscosity which decays logarithmically with time constants of milli-seconds or greater (Grössinger *et al*. 2004).

Quadrature susceptibility measurements using the PIM instrument were undertaken on the majority of the samples as a matter of course, following the A.C. Susceptibility Bridge measurements, thus allowing the calculation of magnetic viscosity (see Chapter 2, sections 2.5.2 to 2.5.4). The intention of using the PIM was to obtain a measure of sample grain sizes, including those samples which had high values of magnetic susceptibility.

The magnetic viscosity of soil, natural clay and heat affected clay samples was as expected, i.e. consistent with an anthropogenic modification of each sample's magnetic properties. However, a significant number of magnetic quadrature susceptibility measurements of those samples of slag and residues which had predominantly glassy structures (blast furnace and lead smelting slags, and glass production residues) could not be made due to the readings proving to be very low and within the noise levels of the PIM instrument, and as a consequence were deemed to be unreliable (see Tables 3.4, 4.1, 4.2 and 5.4). The magnetic viscosities of these samples were "mathematically" suspect (see Chapter 2, section 2.5.4 for the derivation of magnetic viscosity) and resulted in a wider range of viscosity values within each type of material than expected.

Whereas soils and clays are granular in structure, the glassy samples are essentially non-crystalline, as noted above, and the few grains that are contained in the sample structure are associated with specific materials such as silica and free iron or lead. The glassy structure is a complex material which appears to be poorly understood, especially with regard to its magnetic properties (C.M. Batt pers. comm.). The magnetic viscosities of the blast furnace and lead smelting slag samples which were shown through microscopic examination to contain relatively large quantities of free metal could not be reliably measured for the reason given in the previous paragraph. In contrast, the iron smelting slags, containing a lower proportion of glassy material in comparison, have a measurable magnetic viscosity, with an overall mean value of around 1% (Table 3.3); the Myers Wood samples with susceptibilities greater than 2000 x 10^{-8} m^3 kg^{-1} (which as already discussed in Chapter 3 suggests a high proportion of free metallic iron within the slag) have a mean magnetic viscosity of 0.7% (Table 3.3). These latter samples were expected to have higher viscosities (but not significantly so) than the lower susceptibility samples, due to the greater extent of free iron within the sample structure and the ensuing potential effect on the PIM reading, but the results in Table 3.3 show this expectation was not met.

Measuring the magnetic viscosities of the high susceptibility iron smelting slags, the blast furnace slags and the lead smelting slags as a means to investigate whether the free metal, iron or lead, could be identified qualitatively has not been successful with the PIM configured as described in Chapter 2, section 2.5.3. Further investigations are necessary to establish whether the use of magnetic viscosity is an appropriate technique in the examination of slags and residues from iron and lead smelting, and glass production.

11.4 Identification of site components from geophysical survey data

Magnetometer surveys have identified the main components of the medieval/post-medieval industrial sites studied in this research. Comparison of these sites indicates that each type of site is distinct, all except charcoal production sites having recognisable and characteristic components. These components are summarised as follows, using a qualitative assessment of the response of the magnetic anomaly to a magnetometer/magnetic susceptibility survey and taking into account the variability of measured anomaly strength with anomaly depth:

Iron smelting sites: furnace (strong, high valued, concentrated);
surrounding heat affected surfaces (moderate to strong, see Chapter 3, section 3.9 for further details);
tap channel (weak, low valued, barely "visible");
slag deposits (weak to medium, patchwork appearance);
ore roasting area (strong, high valued, concentrated).

Lead smelting bole/bale sites: no concentration of strong, high valued anomalies;
spread of weak, low valued anomalies over and downslope of the site.

Glass production sites: fire trench (strong, high valued, concentrated);
structural remains (medium to high value surrounding the fire trench);
separate annealing ovens (medium to high value concentrations, apparently smaller than the fire trench);
ash deposits (weak, concentrated).

Charcoal production sites: platform (weak, low valued, barely "visible").

Although site components are generally well-defined, with the exceptions of those which are described as having weak or barely "visible" anomalies, there may be occasions when one component appears to be similar to another, either within an industry or between industries, and mis-interpretations of survey data can still be made. The example of iron smelting furnaces and ore roasting areas has already been discussed in Chapter 3, section 3.8.2.5, but it is also feasible for iron ore roasting areas and the combined glass furnace components of fire trench and structural remains to be confused, if no other details are known of a possible industrial site. It is unlikely for glass furnaces to be mistaken for iron smelting furnaces due to the latter being associated with the characteristic component of slag deposits. However, the probability of mis-interpretations being made are considerably reduced when geographical and geological factors are taken into consideration. As already discussed in Chapter 3, iron smelting furnaces are to be found over a wide geographical spread, whereas lead smelting and glass production sites are located in more specific areas dependent on the supply of raw materials. In particular, bole/bale sites are restricted to those geological areas where lead ore occurred and in less than hospitable upland localities; as a consequence iron and lead smelting sites are unlikely to be confused when comparing their respective geophysical survey results (Vernon *et al*. 1999, and 2002). Glass production sites could be located near to iron smelting sites, as suggested from investigations carried out in the Weald by Cleere and Crossley (1985), Crossley (1981) and Kenyon (1967) and in Rosedale, N. Yorkshire, where there is a long history of iron smelting and other major industrial activity. Interpretation of a site as either iron smelting or glass production would depend on the components identified from the survey. Charcoal production sites are usually, but not exclusively, found in wooded areas in the vicinity of iron smelting furnaces (Foard 2001), and as the platforms have weak, low valued anomalies they are unlikely to be mistaken for furnaces. As discussed in Chapter 6, section 6.3.9, magnetometer and magnetic susceptibility surveys can be effective in revealing the shape and extent of the charcoal platform, although in some locations survey data might not indicate any features which could be definitively associated with charcoal production, as was the case at Greencliffe Hag Wood, near Rievaulx Abbey, N. Yorkshire (Chapter 6, section 6.4.5). It is feasible for a survey to reveal one or more high value magnetic anomalies; the absence of any accompanying medium to strong anomalies close to these anomalies would suggest ore roasting rather than smelting. Other medieval and post-medieval high temperature industries, such as tile and brick making, would be expected to have their own characteristic components, in all probability not unlike those of iron ore roasting areas.