Geophysical techniques applied to early metalworking sites

There is no geophysical method dedicated to the location, identification and analysis of early metalworking sites. There has only been limited application of these techniques to the study of such sites. This has been for a number of reasons:

- Primary metalworking sites *(ie* mining, ore processing, smelting), with the exception of iron sites, are located in defined geological regions, and are not, at first sight, suitable for such techniques.
- They are located by other means, usually targeted field walking.
- Early sites are often part of a landscape that has been massively disturbed by later working, and deemed unsuitable for such techniques.
- The most available techniques, *ie* geophysical methods, have not been demonstrated as providing information over and above that which is already known about the site being studied. In most cases metalworking sites are excavated as part of a larger project, and hence have not been sought using field and geophysical techniques.

However geophysical techniques have considerable potential in the study of early metalworking sites and should be applied.

There is a large literature on geophysical techniques (see Gaffney, Gater and Ovenden 1991) and there is the new journal *Archaeological Prospection* dedicated to the subject. So far there is little published on the uses and application of these techniques to metalworking.

The three metalworking processes most likely to be encountered by archaeologists, during site assessment and full scale excavation, are secondary non-ferrous metalworking, iron smelting and iron smithing. Additionally, in certain geological areas the smelting of non-ferrous metals, particularly lead, tin and copper, may be encountered and relevant specialists should be consulted.

The components of these site types are as follows:

- Non-Ferrous Metalworking: Scrap metal, hearths and hearth lining, fuel, crucibles, slags/residues.
- Iron Smelting Sites: Ore and ore processing, fuel, *in situ* furnace remains and furnace debris, slag.
- Iron Smithing Sites: Scrap metal, fuel, hearth base/hearth lining, slag.

Most metalworking sites have associated structures. There are great advantages in smithing and casting indoors, because the temperature of the metal, gauged by its colour, is more easily determined in subdued light. There is little evidence of roofing of smelting furnaces, though provision of dry storage for raw materials might be expected.

The three geophysical techniques most commonly applied in archaeological prospecting are resistivity, magnetometry and magnetic susceptibility. Magnetometry is usually carried out with a fluxgate gradiometer. Magnetic susceptibility measurements may either be made on the soil *in situ* using a field loop or on bagged samples recovered from a site using a bench sensor.

Earth resistance (resistivity) surveys detect changes in the bulk electrical conductivity of the subsurface and thus do not respond to the most characteristic property of most early metalworking features, their strong magnetic signal. Application of this technique is therefore limited and is not considered further.

The relevant techniques are therefore magnetometry and magnetic susceptibility. The responses expected using these on the archaeological remains of the three main processes are considered below. It should be noted that these techniques are often unsuitable for urban sites, where deposits may be deeply stratified and disturbed by latter activities.

Non-ferrous metalworking

Magnetic survey should detect hearths and areas of burning, and possibly large dumps of crucibles, moulds or waste/residues. However the signal may not be significantly distinct from domestic or other hearths.

Iron working sites

The problem of magnetic surveys of ironworking sites is the massive response due to the presence of metallic iron and iron oxides. Top soil usually has a magnetic susceptibility of the order of 1-10 x $10^{-8}m^3kg^{-1}$, a typical fayalitic slag has a response of the order of 35-60 x $10^{-8}m^3kg^{-1}$. Since the slag has a strong remanent magnetic signal that is randomly orientated, magnetic surveys of slag rich areas produce a very 'noisy background' with extreme readings and iron peaks. Also, significant dumps of slag are so strongly magnetic that they distort the magnetic field for several metres around and therefore may mask any response from occupation features (pits, ditches etc).

Iron Smelting Sites

Iron smelting furnaces should provide a strong magnetic response, similar to a pottery kiln, but it is often masked by the response from the slag. Magnetic susceptibility of iron smelting areas using a field coil can provide detailed information about the extent of surface slag spreads since it measures the magnetic susceptibility of a small volume of soil beneath the coil directly (to a maximum depth of about 10cm), and is thus free of distorting effects caused by local highly magnetic objects. High responses may also indicate areas where ore was roasted, screened or stored and where the primary smithing of the iron bloom took place.

Iron Smithing Sites

The magnetic disturbance created by a smithy should be readily detectable by magnetometer and magnetic susceptibility measurements. A ground level hearth should also provide a significant response, but the base of a waist high hearth would not give a response and may be indicated by an absence of response in an area of high values. Use of either a field coil and/or sampling for magnetic susceptibility is of vital importance in the excavation and examination of a smithy. These measurements should be able to detect and determine the scatter of hammer scale which has a response of the order of 75 x $10^{-8}m^3kg^{-1}$ Thus it is possible to recognise the location of hearths and anvils within a building (Mills and McDonnell 1992). Where largely undisturbed working floor deposits survive the area should be gridded and samples (50-100ml) taken at 0.25m intervals.

Conclusions

Whilst more research needs to be done on the application of geophysical prospection to metalworking sites, magnetic survey methods are potentially very useful, both prior to excavation and to define the nature and extent of a site without excavation. Magnetic susceptibility studies undertaken during excavation may allow detailed analysis of iron working areas, particularly smithies.

Other Techniques

Archaeomagnetic Dating:
Materials such as clay, which contains a significant proportion of magnetic minerals, acquire a remanent magnetisation when they are fired. This magnetisation is in the same direction as that of the Earth's magnetic field at the time. The precise direction of the Earth's field varies over time; hence, if a fired clay feature is found that has not moved since was last fired, it is possible to date the firing using the direction of magnetisation recorded in the feature.
The fired clay of furnaces and hearths and slag that has cooled *in situ*, should be suitable for archaeomagnetic dating. However, the presence of the bloom in the furnace will distort the remnant magnetism of a furnace.

Firing temperatures:
Determination of firing temperatures by the analysis of the clay lining has limited benefits. Firstly the temperature varies spatially throughout a furnace, and at a given position during the time of the smelting operation. Secondly, temperatures fall rapidly at the furnace wall, and the wall may be insulated, eg by a bed of charcoal, from the higher temperatures of the combustion zone.

Bibliography

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April 1995