Chapter 3.0 Review of Literature

Numerous works describe smelting techniques. The earliest detailed publications in Europe date from the 16th century and include Biringuccio (c1530) in Italy and Agricola (1556) in Germany. Both books provide practical, authoritative and illustrated accounts of early mining and metallurgical techniques and include details on sources of fuel. During the 19th century, metallurgical processes were recorded by various authors and include Percy (1861 - 1880) and Hunt (1863). The publications of the Newcomen Society (founded 1920), Peak District Mines Historical Society (founded 1959), Northern Mine Research Society (founded 1960) and the Historical Metallurgy Society (founded 1962) provide a platform for both amateur and academic research on the historical and archaeological aspects of both mining and metallurgy. Prior to their existence such papers and articles would have been published in often obscure and localized antiquarian / historical journals or very specialist technical journals. In the last 20 years there have been numerous publications, many orientated towards mining history in the 18th and 19th centuries that give robust accounts of the smelting practices during that period.

3.1 Iron: Literature on the iron smelting process and geophysical surveys on iron smelting sites

3.1.1 The iron smelting process

The iron smelting process is well recorded. Schubert (1957) comprehensively collated available archaeological and documentary sources. Schubert's work provides details of both the *Indirect* and *Direct* methods of smelting when charcoal was the principal fuel. In the last decade the tendency has been for the researchers to pick particular themes. Riden's (1993) gazetteer of charcoal-fired blast furnace sites provides a detailed account of the historical and sometimes the archaeological aspects of that technology. Cleere and Crossley (1995) have concentrated on the Wealden iron industry in southeast England. Their thoroughly researched and detailed account of this once important industry incorporates much archaeological detail and has an extensive site gazetteer. The iron manufacturing industry of Furness, Cumbria has also come under scrutiny. Bowden (2000) has summarized the work of the Royal Commission on the Historical Monuments of England (RCHME) survey on the numerous iron related surface remains and incorporated archaeological surveys carried out by the Lancaster University Archaeological Unit on behalf of the Lake District National Park Authority (LDNPA) (Bowen, 2000,1). The results are a concise well-illustrated and detailed account of this once important industry including its infrastructure, for example charcoal production. In both his principal works Tylecote (1984 and 1990) has attempted to cover all aspects of historical metallurgy. His works cite numerous examples supported by technological and scientific detail and are excellent pointers for following lines of investigation.

Various researchers (Pleiner 1969; Crew 1991b; Sauder and Williams 2002; Ancient Metallurgy Research Group, University of Bradford, 2002/03) have attempted to experimentally duplicate the bloomery iron smelting process with limited success. The experiments generally utilize simple shaft furnace morphology with some small variations in height and internal diameter. Air is supplied by traditional hand operated bellows or by electric blowers. Important variables are the quantity of air introduced into the furnace, the composition of the charge and the working practice, none of which can be accurately identified on archaeological sites by geophysical means.

3.1.2 Geophysical surveys on iron-smelting sites

Despite proton magnetometer surveys being conducted over archaeological sites since the 1950s (Gaffney, Gater with Ovenden 1991, 3) surveys over metal working sites are relatively rare in Britain. Scollar *et al*. (1990, 514) records the first application of magnetic prospection on an iron-smelting site in Britain at Kirkstall Abbey, Leeds, West Yorkshire, in September 1957. Using an Askania instrument a series of measurements were taken in a grid of 1.5m. Three detected anomalies were thought to be a forge.

By the 1960s surveys employing proton magnetometers were becoming common practice. Crossley and Ashurst (1968) refer to Dr. P. Strange using an Elsec proton magnetometer in c1965 to trace the limits of floors at Rockley Smithies, South Yorkshire. Strange (*pers. comm.* 30th July 1999) commented that the survey was not a success due to the amount of extraneous magnetic material around the site. Slag spreads produced a very high magnetic gradient across the site, making it difficult to determine the full limits of iron-working activity. Even raising the detector bottle to a height of 3ft could not reduce this effect. The instrument was eventually used to define the limits of buildings and the extent of the roasting floor. Strange (*pers. comm.* 30th July 1999) stated', *'this did demonstrate quite clearly the unsuitability of the proton magnetometer measuring total field for this sort of site.'* Later surveys with the proton magnetometer at Wakefield (Bartlett 1971, 199) and Lancaster (Jones and Shotter 1988, 90) did little more than identify magnetic anomalies, and an area of burning, and a possible ore roasting hearth, respectively.

In the early 1980s the first fluxgate gradiometer surveys were being conducted over iron working sites. At Lyveden Lodge, Great Oakley, Northamptonshire, David (1981) examined the likely extent of iron working activity. A year later a fluxgate gradiometer survey (David 1982; Yeoman and Stewart 1992) at Mantles Green, Amersham, Buckingham, was able to confirm the presence of Romano-British iron smelting and smithing activity adjacent to the River Misbourne. During the excavation of the site no furnaces were found *in situ*. Most of the smelting / smithing residues were found in a hollow 7.0m across with a surrounding scatter of iron objects (nails, fittings and blades). A large amount of slag had been used to backfill ditches. Other finds in the ditches included a single clay tuyere. It was suggested that a post-built structure north of the working hollow was possibly a workshop related to the iron smelting. It is also recorded that sand and gravel had been mixed with smelting, and some smithing, slag and was laid out as flooring (Yeoman and Stewart 1992). The data in the geophysical report (David, 1982) was presented in trace form and the readings relating to industrial activity did not exceed 100 gammas (nT). Similarly, surveys on a Roman industrial site at Walton-le-Dale, Lancashire (Bartlett 1983) yielded little interpretable geophysical information. Readings were taken every 1.0m but the presentation of the data in trace form made it very difficult to evaluate specific details from areas that generated high magnetic responses. One furnace produced a reading of 600nT. The reliability of fluxgate gradiometer and magnetic susceptibility readings were compromised by magnetic disturbance from modern activities. An earth resistance survey at Chesters Roman Villa, Woolaston, Gloucestershire in 1987 over an area of iron slag produced minimal information on structures (Fulford and Allen 1992). An excavation in 1988 revealed two furnaces that had been enclosed in a timber frame building supported on padstones. During 1991 however, a fluxgate gradiometer was able to define the full extent of the industrial activity as well as slag filled ditches (Fulford and Allen 1992).

Crew has excavated a variety of iron-smelting sites in the Snowdonia National Park, North Wales, ranging from simple shaft furnaces at Bryn-y-Castell (Crew 1984) to a charcoal-fired blast furnace at Dol-gûn (Riden 1993, 69). Crew's research on Bryn-y-Castell, an Iron Age hillfort, commenced in 1979. Several furnaces and spreads of slag have been identified within and outside the hillfort. Minor surveys with a proton magnetometer tried to identify external slag dumps. Crew has excavated a second Iron-Age site at Crawcwellt West, Merioneth (Crew 1989, 1990). Between 1989 and 1991 both fluxgate gradiometer and magnetic susceptibility surveys were used to evaluate a slag dump. By determining the extent of the dump it was possible to make approximate calculations of the amount of slag present (Crew 1991a). A third site in Snowdonia at Llwyn Du, a 14th century bloomery, has also been surveyed in detail (Smith 1995; Crew 1997). In this example, the *Surfer* program was used to present the magnetic susceptibility data. An XYZ (3 dimension) plot has been used by Smith (1995) to suggest the location of a furnace and slag dumps over an area measuring 45m by 25m. By comparing the magnitudes of the different peaks, Smith tried to draw conclusions about the slag type. Crew (1997) reports that one anomaly at Llwyn Du was excavated to reveal the remains of a very well preserved furnace. Crew has also used the *Surfer* program to present data from the Crawcwellt site (Crew 1997). The grey-scale plot enables positive anomalies to be readily identified. Using a contour plot the areas of positive data can be emphasized and furnaces readily identified. Crew also demonstrated how resurveying at a higher resolution (0.25m) identified a double positive anomaly which on excavating was confirmed to be two furnaces. The research in Snowdonia, North Wales, is now concentrating on detailed geophysical surveys and excavation of specific sites (Crew *et al*. 2000a, 2002). By conducting high-resolution fluxgate gradiometer surveys over furnaces before and during excavation, and after furnace removal, clear positive data was obtained. Attempts to date the furnace using the data has been complicated by the magnetic influence of surrounding and overlying slag. Figure 3.1 shows Crew's (1997) comparisons between the same data sets using grey-scale and colour presentation methods. The furnaces show up well on both plots. On the colour plot red and blue have been used to identify extreme positive and negative data, respectively. A more valid comparison would have been achieved if the grey-scale plot had been clipped to a similar data range to the colour plot (Crew 2002). The preferred method of data presentation using *Surfer* can also be achieved using *Geoplot* and to a lesser extent the *Contors* programs, even though there are limitations with setting the scales for presenting the data.

Mills and McDonnell (1992) report on a magnetic susceptibility survey conducted at a smithy at Burton Dassett, Warwickshire. Samples from the smithy floor were taken at intervals ranging from 0.5m to 1.0m. Samples of known weight were broken down and the percentage of magnetic material, mainly hammerscale, in the sample was determined. A magnetic susceptibility survey within the smithy produced values that ranged from 47 to 4018 $x10^{-8}$ m^3/kg. The high magnetic susceptibility values coincided with the areas that had higher proportions of hammerscale in the floor samples. The hammerscale had been separated from the magnetic fractions of the sample. The concentration of high magnetic susceptibility readings were grouped around a structure within the smithy that almost certainly corresponded with the location of the smith's hearth. The results would suggest that a smithy hearth should also be identifiable on magnetometer surveys by examining the distribution of high positive data. This type of comparison has never been duplicated and clearly there is further research that could be conducted on forges. In a more recent publication (Bayley *et al*. 2001, 6) the Burton Dassett magnetic susceptibility survey has been revised and presented as a colour plot. All three published illustrations from the Burton Dassett survey are shown in Figure 3.2 Finney (1997a) has conducted a magnetic susceptibility survey at a smithy at the Ryedale Folk Museum, North Yorkshire, but no comparison has been made with the composition of the floor material.

Apart from Crew's work the only other attempt in Britain, outside this present research, to examine iron working within its archaeological setting has been conducted in Scotland. Photos-Jones *et al*. (1998) undertook a one-year pilot investigation to examine iron-working sites in the Scottish Highlands aimed at developing a methodology for their study and preservation. Five disciplines (archaeology, history, geology, geophysics and archaeometallurgy) formed the basis for the study that was conducted in three phases, (a) evaluation of documentary sources, (b) assessment of the sites and natural environment (geological, geophysical and archaeological) by prospection, and (c) examination of ore sources and residues. The three sites they presented are examples of small-scale and large-scale bloomeries and a water-powered site (Photos-Jones *et al*. 1998). The majority of the sites are undated, although C14 dating indicates medieval usage for some of them and they generally consist of small mounds (average 3m by 5m by 1m) of broken slag adjacent to furnace remains. The furnaces are usually in a poor state of preservation (Photos-Jones *et al*. 1998). Geophysical surveys were conducted to identify the positions of furnaces, hearths and working floors. Some of the sites covered small areas, and surveys were often confined to one 20m grid. Survey resolution was usually 1.0m. Fluxgate gradiometer surveys were used on all sites. Earth resistance was used to locate water channels and to confirm the magnetic data where structures had been identified. The Tamheich Burn fluxgate gradiometer survey revealed two positive anomalies. The highest value of 360nT

(Iain Banks, *pers. comm.)* is associated with the slag dump. A furnace on site produced a value of approximately 100nT. On excavation, the remains of the furnace bowl measured 0.30m by 0.32m. A vitrified clay lining was intact on three sides and up to 0.30m high. The furnace had been enclosed in a stone structure. The depth of the furnace is not recorded. At the Allt na Ceardaich site the highest positive value (438nT (Iain Banks, *pers.comm.*)) is associated with the furnace. Again this furnace was enclosed in a stone structure. The vitrified furnace lining was about 10cms below the surface. The Fasagh site was probably water-powered. The fluxgate gradiometer values associated with the slag dumps fell between -200 and 200nT. The two anomalies exceeded the instruments over range value (2047.5nT) (Iain Banks, *pers. comm.*). Excavation confirmed the presence of an iron sheaved anvil block. Unfortunately the paper shows the geophysical surveys as trace plots and there is not a vertical scale for full assessment of the anomalies to be made. The Fasagh iron-works survey shows several linear anomalies, but no attempt has been made to relate them specifically to the topographical evidence other than the two anvil anomalies identified by excavation (Figure 3.3). Clearly there is more information that could have been obtained from the geophysical data. The second part of the work (Hall and Photos-Jones 1998) examines the likely sources of iron ore; particularly bog iron ore, thought to be the primary ore source on many early sites (Hall and Photos-Jones 1998).

Young (2000) reports on a survey of a possible water-powered bloomery site near Miskin, South Wales. A fluxgate gradiometer survey recorded anomalies of up to 1700nT on two furnaces. Bellamy *et al*. (2001) provide details of an excavation of a geophysical surveyed site at Cendry Holmes, Northamptonshire. The magnetometer survey was conducted at 1.0m resolution. Five high value anomalies were identified ranging from 44 to 66nT and they were interpreted as possible furnaces or ore roasting hearths. Several weakly contrasting linear anomalies were confirmed by excavation to be ditches with some slag backfill. Figure 3.4 is a reproduction of the survey together with the excavation plan of the positive anomaly, a furnace base, together with a tapping channel containing *in situ* slag. It is probable that if this site had been resurveyed at a higher resolution, for example 0.25m, then a more reliable geophysical interpretation could have been made to assist in the planning of the excavation.

Recent work by Crew (2002) has provided an in depth study of how magnetometer surveys can be used to map iron-working sites. Combined with reliable excavations and archaeo-magnetic sampling, Crew has attempted to date furnaces and elaborates on the difficulties experienced. He concludes that due to on-site complications, for example other sources of magnetic signal (*in situ* tap slag etc.), this might only in rare circumstances be achievable. Many of Crew's surveys are of high resolution but only concentrate on the furnace anomaly.

Elsewhere, Challis (2002) reports on excavations at a bloomery site at Stanley Grange, Derbyshire. The published fluxgate gradiometer survey identifies a number of intense magnetic anomalies that prove to be furnaces.

Powell *et al*. (2002) investigated the relationship between magnetic response, magnetic susceptibility and mineral composition. Findings suggest that a combination of magnetic and material analysis can indicate how such smelting sites functioned. There was a good correlation between the magnetic anomaly and the physical dimensions of the furnace (including the furnace fill, vitrified lining and baked clay). A specific conclusion was *'that it is difficult to classify the magnetic properties of slag in general, but also to predict the response from any slag deposit'* (Powell *et al*. 2002).

Whilst geophysical surveys over bloomery sites have been relatively common, the later phases of charcoal based iron smelting technology have received little attention. This is possibly due to the physical difficulties to geophysically survey such sites. Many of these sites in Britain contain structural remains and have become densely wooded after abandonment thereby prohibiting large scale surveys. Apart from those covered by the present research (Vernon *et al*. 1999b) there is only one other known geophysical survey of a charcoal-fired blast furnace site (Jones and Maki 2000) and this example is in the USA (See Chapter 5.1.4.1.1).

Slag pit furnace surveys have dominated geophysical research in continental Europe. They are located in Denmark, northern Germany and Poland. Those in Denmark have been magnetically surveyed since the early 1960s using total field magnetometers (Smekalova *et al*. 1993). Smekalova *et al*. (1993) and Smekalova and Voss (2002), and based on earlier research by Linington (1964), have promoted the slag pit's magnetic anomaly as a steeply dipping, inclined magnetic dipole a model that corresponded with most measured anomalies. This research has also been augmented by research at the Department of Physics, University of Kiel in the 1980s. Using high-resolution grids, their surveys have identified combined magnetic anomalies under 1 to 2m of sand. Further research has now concentrated on the organization of metallurgical operations, precise dating and the significance of iron production on the local settlements. In 1990, 1000m^2 were surveyed with a proton magnetometer and excavated. Twenty-one slag pits together with two longhouses were discovered (Smekalova *et al*. 1993). Abrahamsen (2001) has developed the research and included archaeomagnetic dating. He concluded that slag (in this example the slag pit furnace) is often magnetically inhomogeneous and the physical shape of the slag body varies. The thermo-remanent magnetism is typically not uniform and this may explain why individual slag pits have rather poor directional records of the earth's magnetic field. Slag pit geophysical surveys are usually presented as contour plots (Figure 3.5).

Slag was the subject of Al-Mussawy's (1990) original research conducted in the Stumpf Forest, Germany. Comparisons were made between the amount of slag, chemical composition and magnetic susceptibility. Magnetometer surveys were conducted over slag dumps. In the study, slag was grouped based on chemical composition and the magnetic properties of each group examined. He concluded that in young (*sic*) (recent) slag with metallic iron forming 3 to 5% volume, the iron is the main cause of magnetization. In older slag, magnetite is the main magnetic component together with small amounts of metallic iron, pyrite and wüstite. Unfortunately the fact that different processes may have produced the slag never comes to the fore in the research. The younger slag for example, described as dark green and glassy, may have been produced by a charcoal-fired blast furnace**.** The older slag is dark grey and porous and exhibits flow features, almost certainly bloomery tap slag. Al-Mussay further concludes that the presence of 'modern' (presumably young) and old slag together confirm that they were transported from their original smelting place. This may not be correct, as a high bloomery for example could produce either form of slag (Vernon *et al.* 1998a, 77). One finding was the apparent difficulty to differentiate between anomalies produced by small-buried slag tips and those generated by an oven (*sic*) (furnace).

Elsewhere in Europe, most surveys have concentrated on individual iron working sites. The sites range from Iron Age / Roman (Hesse *et al*. 1986) to Medieval (Gömöri and Wallner 1984; Cech and Walach 1988). Generally the surveys have been reproduced as contour plans and have usually related specifically to archaeological excavation. Most of the positive anomalies are usually below 150nT. During the 1990s, grey-scale techniques started to replace contour plots. Eschenlohr (1995) in the Swiss Jura identified iron-working anomalies with values up to 700nT. Several surveys (Fluck 1990; Cech and Walach 2000) have been conducted over forges, where iron is manufactured into artifacts. Magnetic anomalies have been used to identify the location of the forge and slag dumps. Cech and Walach (2000) have attempted to classify the smithy slag by lump size, weight and magnetic susceptibility. The latter is measured in the field with a "Kappameter". Their initial findings suggest that it may be feasible to classify slag by this method. The magnetic susceptibility for the slag from four sources had a random distribution indicating a similar source whilst clustering of lump size from different sources suggested different techniques to produce it. Fluck has conducted numerous geophysical surveys on mining and smelting sites in the French Vosges. Fluck's (2000, 176) latest publication is illustrated with a colour plot of a magnetometer survey with the main positive anomalies specifically identified.

3.2 Lead: Literature on the lead smelting process and geophysical surveys on lead-smelting sites

3.2.1 The lead-smelting process

There are references to lead mining and smelting in the historic record from about the 13th century onwards (Kirkham 1971). However, the development of smelting techniques is poorly documented. The 'Boles and Smeltmills' Seminar in 1992 (Willies and Cranstone) was the first attempt to address this discrepancy. It examined a wide range of lead smelting issues for the bale / bole through to reverberatory smelting. However, for each topic discussed many new issues were raised, and ten years after the seminar those queries have still not been resolved.

Murphy and Baldwin (2001, 2003) have examined numerous Swaledale bole furnaces and have concluded that the majority of boles appear to have been small affairs. Small quantities of pure galena were smelted as a single batch with the lead trickling freely from under the fire. A few sites have associated charcoal dumps. With this potential to reach higher temperatures the re-smelting of slag could not be ruled out. More likely, it is suggested, that the charcoal was used for smelting a mixture of galena and gangue minerals when supplies of pure galena were exhausted.

3.2.2 Geophysical surveys on lead-smelting sites

The relative absence of reference material detailing the application of geophysical methods to evaluate lead smelting sites is also conspicuous. During the course of this research three lead smelting sites have been surveyed which builds on the earlier work of McDonnell *et al*. *(*1992) and Hamilton (1998) and Hamilton *et al*. (1999) on sites in Swaledale. The first recorded geophysical survey was conducted in Derbyshire. Willies (1990,1), refers to a proton magnetometer survey over bole sites on Beeley Moor. The survey indicated that the boles were six to ten metres apart, with bottoms about a metre in diameter. The survey by McDonnell *et al*. (1992) was conducted with a fluxgate gradiometer on a bole site at Grinton, Swaledale but was inconclusive on either the form or the location of the bole. A further survey conducted on the site by Evans in 1993 provided little new information. Vernon *et al*. (1999a and 2002) report on the current research and compare the geophysical properties of lead, iron and copper smelting sites.

Interest in the geophysical properties of lead smelting sites on continental Europe is confined to the Black Forest, Germany (Goldenberg 1990) and the Vosges of France (Fluck 1990; 2000). Most published geophysical surveys are of iron working processes that supported the lead working. Fluck (1990) for example has identified a forge at Le Samson silver lead mine, Sainte-Marie-aux-Mines. A variety of geophysical techniques were applied to Saint-Jean-Furstenbau lead mining settlement in the central Vosges. Some mining structures were identified including the cutting to the mine adit. A forge was also identified by magnetic prospection. Attempts with ground penetrating radar provided little detail due to target depth and multi-diffracting ground (Hulot *et al*. 1995).

3.3 Copper: Literature on the copper smelting process and geophysical surveys on copper-smelting sites

3.3.1 The copper-smelting process

There is ample evidence for widespread Bronze Age copper mining in Britain (Timberlake 2001). However until recently there was no evidence at all for smelting, consequently any descriptive work was based on sites excavated in southern Spain (Rothenberg and Blanco-Freijeiro, 1981) or Timna, Israel (Rothenberg 1972). Spreads of copper slag dating from the

Bronze Age have been recorded on the Great Orme, North Wales, but unfortunately the furnace that produced them was not identified (Anon 2004). O'Brien's (1994) study of southern Ireland again records mining activity with little indication of smelting.

The introduction of German mining and smelting techniques during the Elizabethan period to revitalize the British copper industry is described by Bridge (1994) and Smith (1994) and both works provide some detail on the smelting techniques that prevailed in this period.

Only in the 1700s with the introduction of the reverberatory furnace are there clear descriptions of the smelting process, for example at Parys Mountain and Amwlch, north Wales (Hope 1994) and south Wales with the development of the 'The Welsh Method' (Hughes 2000), and at Middleton Tyas, North Yorkshire (Hornshaw 1975).

3.3.2 Geophysical surveys on copper-smelting sites

There are very few examples of published geophysical surveys conducted over copper smelting sites. Researchers at Leoben University, Austria, have reported on various metal mining sites in the Alps. Presslinger *et al.* (1988) reported on geophysical surveys on copper works in the Mitterbergealpe in Austria. A magnetometer survey over a smelting site identified an ore roasting area (maximum value c30nT), a furnace and a slag dump (maximum value c50nT). The furnace site produced values of about 5nT (See Figure 3.6). The research also compared the magnetic susceptibility with the density of samples from various locations. The samples from each locality were clustered with minimal cluster overlap (See Figure 3.7). The research also illustrated how Alpine furnace dimensions tended to decrease through the Bronze Age and into the Iron Age. Cech and Walach (1995) have published further geophysical surveys of copper smelting sites but the data consist of contour diagrams of the geophysical data with no interpretation beyond that of identifying anomalies. The latest research by Cech and Wallach (2000) includes magnetometer surveys over medieval water-powered smelters in the Angertal Valley, Gastein area, Austria. The surveys identified slag spreads and the site of the smelter.

Cyprus has long been recognised as a major copper producer in the Bronze and Roman periods. Since 1992, the Sydney Cyprus project has been carrying out a large archaeological survey in the Politiko area of the Troodos Mountains. In 1996 a large quantity of slag and refractory material were discovered. An excavation confirmed that the site was a small copper smelting workshop. Prior to the excavation the University of Reading conducted a fluxgate gradiometer survey and detected several anomalies. The anomalies proved to be induced by geology rather than archaeology. The report on the excavation indicated that the furnaces found in one of the trenches were constructed from coarse refractory clay with an outer diameter typically between 42-44cm (Anon 1997). A further account of the excavations (Anon n.d.) indicates that the geophysical survey was able to detect the course of an ancient stream in which a slag tip was found.

Geophysical surveys have also been conducted on copper smelting sites in Jordon. The settlements, mining and smelting sites associated with the copper deposits at Jebel Hamrat Fidan, Jordan have been extensively surveyed archaeologically (Witten *et al*. 2000). The sites contain large quantities of copper slag, ores, copper workings etc. Geophysical methods have included magnetometer and ground penetrating radar surveys that have detected buried walls. It is reported that further geophysical work will be undertaken to delineate copper deposits and mining voids (Witten *et al*. 2000, 148). Geophysical surveys covering the copper smelting areas have apparently not been published.

In Britain only the survey of the Ellastone copper smelting site, Staffordshire, have been published (Porter and Robey 2000, 25; Vernon *et al*. 2002). It is almost certainly the first copper-smelting site to be geophysically surveyed in the British Isles.

3.4 Tin: Literature on the tin smelting process and geophysical surveys on tin- smelting sites

3.4.1 The tin-smelting process

Tin deposits are relatively rare in Europe. Apart from England, economical reserves are found in Brittany, France (Bouladon, 1989, 39-42), northern Portugal (Thadeu, 1989, 209-214) and adjacent areas of Spain (Vázquez Guzmán, 1989, 127-138) and in southeast Germany (Baumann *et al*. 1986, 315-317).

The recent investigations at Crift Farm (Buckley and Earl 1990; McDonnell, 1993; McDonnell *et al*. 1995; Malham *et al*. 2002) is the only detailed account of a pre-blowing house tin smelting site and will be discussed later (Chapter 5.4.2.1.2).

Occasional papers in the publications of the Trevithick Society (McDonnell, 1993; McDonnell *et al*. 1995), Historical Metallurgy Society (Malham *et al*. 2002) and the Peak District Mines Historical Society (Newman, 1996) have covered various aspect of tin smelting. Both Greaves (1981, 1984) and Gerrard (2000) have documented the distribution of medieval blowing houses. Gerrard (2000, 19-21) provides the only comprehensive summary of early smelting technology and comments on the finds of slag and cassiterite in Bronze and Iron Age villages and describes the simple shaft furnace type technology.

3.4.2 Geophysical surveys on tin-smelting sites

There is very little published research on early Cornish tin smelting sites and only one, Crift, Cornwall refers to geophysical surveys (McDonnell, 1993; McDonnell *et al*. 1995). Merideth (1998) conducted topographical surveys of tin mines and smelting sites in the northwest of Spain and Portugal, but only provides minimal details on the smelting activity.