



Bloomery iron smelting slags and other residues

Introduction

There are many variables in the smelting process, including the ores, the fuel and the clays used, the furnace construction, the method of blowing the furnace and the way in which the slag and bloom were removed. These result in a wide variety of slags and other residues. Although it is possible to define and describe some basic types of slag, in reality there is a more or less continuous transition from ore through slag to the finished iron. The materials to be described fall into four broad groups - the raw materials, the structural evidence, the waste products and the bloom. There is no consensus on the terminology for some varieties of slags. This is an area of active debate and ideas are still changing. The approach which has been adopted is to give brief descriptions of the materials, relating them, as far as possible, to the process. *The residues which may be found on archaeological sites are indicated in italics.* It must be stressed that few of these residue types, as individual pieces, are diagnostic of smelting and that the interpretation of the material can only be based on a consideration of the whole of the assemblage recovered from a site. The variety of slags and other residues is such that each site can produce its own specific types and so the archaeological response to this material, in terms of excavation, recording, sampling, post excavation treatment and interpretation needs to be both flexible and site specific. There are only a few specialists with experience of iron-working slags and the initial processing and interpretation must be carried out by

the archaeologist. It is hoped that these notes will assist in this process, not least by making clear the difficulties of identification and interpretation.

Iron Ores

These can occur as raw ores, as roasted ore pieces and as roasted ore fines. *Raw ores* can be difficult to recognise, especially as they rarely occur in any quantity on archaeological sites. They are not necessarily dense or brightly coloured, but they would usually stand out against the general background of stone which occurs on most sites. *Roasted ores* are more obvious, being usually a red or purple colour, or more rarely grey-black. They are most commonly found on site as small particles of *ore fines* which can occur either where the ore was roasted, crushed or stored, or in smaller concentrations in or around the furnace structures.

All finds of ore are potentially important as they provide a basis for reconstructing the metallurgical processes and for estimates of the quantity of iron likely to have been made. It is always possible, of course, that the ores found on site were discarded because they were of too poor a quality to be used, but that is a problem for the specialist.

Charcoal

This was the fuel used exclusively for bloomery smelting. There are no known early charcoal production sites prior to the Medieval period, and they are rare until the 18th century. It is likely that at early sites charcoal was made nearby and this possibility should be borne in mind

if large concentrations of charcoal are encountered. In some parts of Europe charcoal was made in small pits adjacent to the smelting sites, but as yet there is no evidence for this from Britain.

Charcoal is not necessarily found in abundance on smelting sites as it was too valuable a material to waste. Samples, especially from features, are potentially important not only for dating but to identify the species used and as an indication of potential woodland management. Charcoal has a small percentage content of inorganic material, which can fuse to form *fuel ash slags* and which can make a significant contribution to the chemistry of the other slags formed in a furnace. Fuel ash slags are light, vesicular and fragile, so they are often found as very small fragments, and their colour can vary enormously. They are rarely found in any quantity on smelting sites, as the fuel ash invariably becomes incorporated with the other slags.

Clay and furnace structure

Considerable quantities of clay would have been used in the construction of furnaces and it could have been an important aspect in the location of a site. Stone and tile can also be used as part of the furnace structure. The clay is often heavily grogged with small stones and pieces of slag. There is some evidence that better quality clays were prepared with a temper of sand or fine charcoal, which would have been used for repairing the high temperature zone of the furnace. Clay bricks of a distinctive shape have been found on some Roman sites. The high temperature in a

furnace produces *vitrified clay lining*, though heavy vitrification is usually limited to a zone above the blowing hole and elsewhere in the furnace the clay will be baked to a greater or lesser degree. The inner surface can be vitrified for 10mm or more and it usually has a surviving backing of baked clay, either oxidised red or reduced to a grey colour, depending on its original position in the furnace. Indications of furnace repair are often found as multiple layers of vitrification. The clay can also be coated with slag and it can react with the slag to form thicker accumulations of furnace lining reaction products.

It is rare that much furnace structure is found *in situ* and as it is rather brittle it is usually found in relatively small pieces. Fragments of vitrified clay lining can, however, give useful information both on the internal shape of the furnace and especially on the method of introducing the air. On early sites this is usually through a simple circular *blowing hole* in the wall of the furnace, but this would normally only survive as a fragment of vitrified clay with a distinctive curved shape. Some Roman sites have produced evidence for clay *tuyeres*, and in the Roman and Medieval periods there is some evidence for the use of replaceable *block tuyeres*. These are separate circular or rectangular blocks of clay, with a blowing hole, which are set in place in a prepared cavity in the furnace wall.

It can be difficult to decide if individual pieces of vitrified clay come from a furnace or a hearth structure. Smelting sites usually produce significantly larger quantities than smithing sites and the degree of vitrification can be much greater, but this depends both on the refractory nature of the clay and the original location of the material within the furnace or hearth.

The less baked and sunbaked portions of furnace structures rarely

survive and this can give a misleading impression of the thickness of the furnace walls. The best indication of this is where the lower part of the furnace structure survives *in situ* as a clay lined bowl in the subsoil. This is not, however, the remains of a so-called bowl furnace, but the base of a taller shaft furnace. Some designs of furnace are partly built into banks of clay, which can result in a substantial proportion of the furnace surviving. The size of a furnace should be recorded as an internal diameter, with an estimate of the likely wall thickness. All furnace structure *in situ* potentially can provide good material for archaeomagnetic dating.

Slags

The easiest way to describe the slags is to relate them to the smelting process. Normally, of course, the majority of slags are found mixed together, often in a dump outside the building in which the smelting was carried out. Very few smelting slags are found *in situ* and if a large accumulation of slag is found in the base of a furnace, then there is a possibility that it was a failed smelt and that the furnace was abandoned.

One of the particular difficulties facing the archaeologist and the metallurgist in interpreting site finds is that they may have altered considerably since they were formed due to secondary corrosion products which can alter the colour and surface texture of slags and, in extreme cases, can change their morphology completely.

As pieces of ore pass through the furnace they become reduced progressively to particles of iron surrounded by envelopes of slag. When they enter the hot zone above the blowing area, the iron particles begin to coalesce and eventually they become welded together to form the bloom. The bloom forms just below the blowing hole and is usually attached to the furnace wall,

slowly subsiding under its increasing weight. The slag, being more liquid, continues to descend into the lower part of the furnace, though a significant proportion of it remains attached to and trapped in the bloom.

Some of the ore and intermediate products pass through the furnace, especially in the early stages of a smelt before the bloom has begun to form. In the base of the furnace there may be pieces of *reduced ore*, usually fired to a grey colour, either with their morphology unchanged, or partially slagged. Much of this material will occur in the form of highly *magnetic dust*. Some of these particles of ore which have begun to slag can have thin hollow *slag shells*. These shells are very fragile and they can fragment into small magnetic flakes which could be mistaken for hammer scale, but they usually have a distinct curved surface which can be recognised when larger pieces survive.

There will also be small separate pieces of slag, which have flowed into the lower cooler charcoal bed and have frozen there. This material can take the form of small *slag spheres*, which can be either light and vesicular or dense and solid, with a variety of colours and textures. The most numerous pieces are *slag prills*, which have intact cooling surfaces and frequent impressions of the charcoal in which they have cooled, giving them a very contorted shape. Prills are usually dense, with either a dull or a vitreous surface, and they can vary in size from a few grams to tens of grams. Usually the majority of the internal slags coalesce into larger accumulations of *furnace slag*, which are simply a larger variety of the prills described above and can weigh up to 500g or more. The larger pieces are often not well cemented together and can be broken into fragments with sharp angular fractures. Most of these slags are relatively dense but some varieties, with the same external

morphology, can be much less dense, with a variable quantity of vesicles caused by gas bubbles. This type can also produce *slag shells*, similar to those already described. Towards the end of a smelt, when the lower zone of the furnace is hot enough, individual *internal flows* of slag can reach the base of the furnace before freezing and can thus have a smooth lower surface, sometime with clay or stone fragments attached. These are very similar to tap slags, but they form only a small proportion of the total. Large air bubbles in these flows can form *envelopes of slag*, which can also fracture into thin shells or sheets.

In a non-slag tapping furnace, these furnace slags are the most recognisable waste product and can occur in relatively large quantities. However, in such a furnace the separation between the slag and iron is not so complete and many of the slags produced can be iron rich. When found on archaeological sites, of course, these slags generally have heavy corrosion products and will have lost their original texture and shape. Such *amorphous* or *unclassified slags* can account for more than 50% of the material found on early sites.

Some sites have evidence for *raked slags* which have been pulled out of the furnace in a pasty state. These can be in the form of very distorted lumps or, if the slag has been slightly more fluid, as small irregular cakes.

In a slag-tapping furnace enough slag flows into the bottom of the furnace to transfer sufficient heat for the slag to remain liquid, so that it can eventually flow out of the furnace. *Tap slag* can vary from individual runs of a few hundred grams to accumulations weighing 10 kg or more. The characteristic feature of these slags is their ropey structure, resulting from consecutive flows of slag. The surface of the flows can be rippled or smooth, depending on the speed with which

they have run out of the furnace. They are usually dense with a grey to black colour and have a dull angular fracture. Calcereous ores can produce lower density tap slags, which can have a pale coloured surface and a black vitreous fracture. Sometimes tap slag has sand or clay accretions on the lower surface but the majority has a characteristic basal texture resulting from the slag cooling on a charcoal bed.

Tap slags are brittle and can fragment into small pieces. However, they often retain indications of the shape of the U or V-shaped tapping channel through which they have flowed, as *slag runners*, or of the shape of the shallow pit into which they have been tapped to form *slag cakes*. Individual pieces can indicate clearly the way in which the slag has accumulated in several layers, which can reach a thickness of 50mm or more. If the slags have cooled sufficiently between flows, they can fragment along the cooling surfaces into thinner sheets. Some fragments of tap slag have a distinctive bright red colour, caused by surface oxidation of the slag when it has remained in the furnace arch for some time. An estimate of the weight of slag cakes is important, as this is one of the best indications of the size of an individual smelt.

In some cases slag can accumulate in the base of the furnace, to form a *furnace bottom*. These are usually large accumulations of dense slag, weighing from about 2 kg upwards and they can retain the shape of the furnace base, sometimes with part of the baked clay structure still attached. Furnace bottoms sometime retain small necks where the slag has run into the tapping channel. Some specialised types of furnace, known in Britain only from the post-Roman period, have pits below the furnace, in which the slag collects to form large *slag blocks*. In this case, the furnace superstructure may have

been slight enough to have been easily rebuilt or moved to another location when the slag pit was full.

The bloom and related products At the end of a smelt the raw bloom is usually attached to the front wall of the furnace, just below the blowing hole. Around the top edge of the bloom there can be a 'crown' of partly sintered iron particles, but these rarely survive on archaeological sites either because they would be re-cycled by the smelter, or because they would corrode quickly.

Attached to the bloom will be a quantity of slag which can be either the dense or vesicular furnace types. If the bloom is removed from the furnace when it is cold, these peripheral slags would be hammered off before bloom smithing commences and some sites have produced evidence for this in the form of small shattered fragments of slag.

Between the bloom and the furnace wall there can be a zone up to 20mm thick of *dense blocky slag*, which is a partly a result of the furnace slag reacting with the clay lining. This is relatively homogenous and breaks off from the bloom with a characteristic angular fracture.

If the bloom is removed hot from the furnace, for immediate refining, the residual furnace slags can also be cleared out when hot, which can result in them having a very contorted shape, similar to *raked slags*.

Raw blooms have not been found on archaeological sites, as the first stage of refining would normally be carried out at the smelting, or primary production site. The refining of the bloom produces some very distinctive residues and the resulting *smithed bloom* can be in a variety of forms, such as a sub-circular cake or as a rough cuboid. These residues and products will be discussed in more detail in Datasheet No 6.

Other related evidence

There are no known tools specific to the smelting process which survive in the archaeological record. Neither is there any direct evidence for the form of the bellows, except in some later literary sources. Some prehistoric sites have produced evidence which may be related to bellows, such as low-angle stakeholes (which would have held flexible stakes giving the return action for foot operated bellows) and shallow hemispherical pits with large stakeholes, which may be related to the bellows design. The excavation of a Medieval furnace in the Forest of Dean has produced a large raised platform in front of the furnace, which was probably a base for the bellows.

Some iron-working sites have produced evidence for fire-lighting, either as lumps of iron-pyrites used to produce sparks, or fire-drill stones, with cup-shaped hollows, which would have been used as bearings for a fire drill. Fire, of course, would have been important on sites of all types, so such evidence should perhaps be found more commonly than it is. Perhaps the most important evidence related to smelting are the buildings or structures in which the work would have been carried out. Shelter would have been essential for the storage of both ore and charcoal and for protecting the furnaces, which would have represented a considerable investment of time and materials. Examples of round stake-wall smelting huts have been found on prehistoric sites and large square post-built shelters on Medieval sites. If a site has not been ploughed, it should be possible to re-construct the layout of such installations with some confidence.

Summary

Few of the slags described above are individually diagnostic of smelting. The only certain indications are the presence of ores and tap slags, though the latter are sometimes

found out of context and in later periods may have been transported some distance. The interpretation of iron-working sites is fraught with difficulties, not least because of the variety of slags and our lack of detailed knowledge. The literature on the topic is replete with incorrect identifications and dubious interpretations which can be very misleading.

One of the most important aspects of recording an iron-working site is the quantification of the slags, preferably classified into a site-type series. This statistic is vital, for the interpretation of the site processes, for estimating the scale of production and the resources required. If a site is only partially excavated, some effort should be made by geophysical survey or sampling to estimate the total quantity of slag. This topic will be treated at length in a later Datasheet.

The amount of slag which can be expected at a primary production site varies considerably with the period. On prehistoric sites even a few tens of kg is significant, as very few production sites are known and the largest site has only about 5 tonnes. Roman and Medieval sites can vary from say one tonne to hundreds of tonnes. Slags are not datable in themselves, but consideration of the types which occur and their quantity may give some indication of the period.

The location of a site can be important. Early sites can be located more or less anywhere, mainly depending on the availability of one or more of the resources. Sites with large slag heaps which are located by a large stream or river may be later Medieval water-powered bloomeries.

In geographical terms, iron production sites can be expected anywhere in Britain. For example, in the last decade major early iron-working complexes have been discovered in East Yorkshire, Lincolnshire and in the Blackdown

Hills of Devon, where previously there was little known evidence. Iron smelting has passed through a long and complex sequence of chronological and technological development, which has ultimately been driven by economic, social and political circumstances. Although we have a broad outline of these developments there is a lack of detailed knowledge of the distribution of the industry, its scale, its organisation and the details of the technology used at various periods. In general, there are relatively few well excavated or well recorded primary production sites from any period prior to the introduction of the blast furnace.

References

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