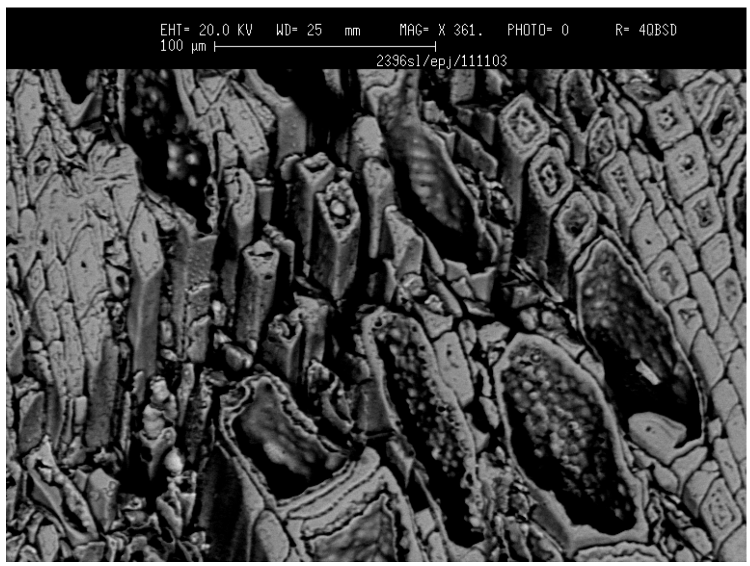
Scottish Analytical Services for Art & Archaeology

A site like KAY: ***"…a lively workplace, manned by a number of workers engaged on various tasks while their customers wait around for their work to be completed".***

The Examination of Metallurgical Waste from Killickaweeny, Co Kildare



SCOTTISH ANALYTICAL SERVICES FOR ART & ARCHAEOLOGY

SASAA 112

This technical report has been commissioned by Irish Archaeological Services Ltd, Dublin, Ireland.

7 Belgrave Terrace
Glasgow G11 6AF
Scotland, UK
Tel/fax: +44-(0)141 337 2623
sasaa.enquiries@supanet.com
www.sasaa.com

The technical Examination of Metallurgical Waste from Killickaweeny, Co. Kildare

by

Effie Photos-Jones

SASAA 112
Scottish Analytical Services
For Art & Archaeology
Glasgow,
Scotland, UK
January 2004

The technical Examination of Metallurgical Waste from Killickaweeny, Co Kildare

1.0 Introduction: setting the scene

1.1 The site

The purpose of this report is to shed light into the nature and extent of metalworking activities within the excavated remains of a medieval and, on account of the material finds, high status site at the townland of Killickaweeny (KAY) in N E Kildare, in the province of Leister, dated to the 9^{th}-10^{th} c AD (Walsh 2003). Fundamental to the understanding of the site is the characterisation of a number of features (pits, gullies etc), in association with the metallurgical waste (MW) found within, and in the context of other craft-based activities, like bone working, potentially practiced on site.

The site (see Figure 1a) consists of a ditch c. 60-70 m in diameter enclosing four structures and numerous smaller features. The metallurgical area is to the north of Structures B and C and is characterised by a number of potential bowl furnaces, curvilinear gullies, peripheral features and a large feature assumed to be a cistern (C364). An additional feature said to be a metallurgical furnace is located to the NE of the site (C861).

Although there are a number of published sites with evidence for metalworking activity which date to the 9^{th}-10^{th} century AD, (see section on bloomeries in Ireland) there is only limited data regarding the technical characterisation thereof. Recently the present author completed the technical examination of a set of thirteen sites along the KEK-M4 motorway scheme under contract to ACS Ltd, Drogheda, Co Louth (see series of Photos-Jones 2003 reports under ACS LTD). JT1 is located only 7km to the west of KAY. The KEK-M4 /ACS data and results produced a convenient typological grouping for bowl furnaces and other ancillary features like bloom smithing hearths and charcoaling platforms, which can be used as a working model for other sites. According to the above, the bowl furnace is an oval or sub-circular structure of c. 30-40 cm or 50-60cm in diameter and c. 20cm deep, usually lined with clay, with vertical sides and a flat base. Bloom/smithing hearths are usually rectangular c.1m x 2m while charcoaling platforms are larger (c. 1.5m x 3m). A variation to the bowl furnace/bloom smithing hearth is the combined version thereof with the bowl furnace stepped down within the bloom smithing hearth. Cleared areas with slag and charcoal next to the bowl furnace might have been created for the positioning of the bellows and will be evident to the archaeological record as shallow pits.

Most of the KEK-M4/ACS sites present an image of a lone smith making/working iron for his own use by returning to sites which might be termed “industrial grounds”. These are localities which must have combined availability of ore and fuel some in the proximity of the smiths’ settlement, others not evidently so. JT1 is different in that it is almost certain that many smiths would have joined forces to make iron on site; however, the absence of domestic occupation is puzzling (Clark 2003). KAY on the other hand which is contemporary with one phase of JT1 not only shows evidence for domestic occupation but is classed as a high status site. What type of a community did it serve? Is it a case of a smith catering to the needs of a lord and his estate? The documentary evidence from that period focuses on the Irish Tract Laws (Scott 1983). The documents clearly suggest that the location of the smithy was within an active community since issues of “Health and Safety” or animals and humans are particularly stressed by the medieval lawmaker. Does the archaeological evidence at KAY assist in any way in the interpretation of the documentary evidence?

In this report a number of questions are addressed: Which features can clearly be characterised as bowl furnaces and which as bloom/forging hearths? What is the nature and role of features C364 and C861 as cistern and metallurgical furnace respectively? the role of gullies and peripheral features? In reference to metalworking, are there activities both primary (smelting) and secondary (smithing) clearly discernible on site? Finally what is the relationship between those pits with burnt bone and clay and those pits with burnt bone and metallurgical waste? Is the presence of burnt bone within a metallurgical pit accidental or intentional? How does each individual group distribute within the site? In both KAY and Johnstown 1 (JT1), the association of the metallurgical quarters with a trough, which might or might not be contemporary with the metalworking activities, is still an issue which needs to be addressed.

1.2 Report Layout

Section one sets the scene for the site and provides the set of questions which are addressed within this report. **Section two** provides the methodological approach for the examination of both the artefacts and the features from which they derive and outlines the analytical techniques used. **Section three** gives the background for ore and fuel availability and typology. **Section four** examines the published archaeological evidence for the Irish bloomery and outlines the principles of bloomery iron making in general. **Section five** examines the materials to include soils, slags and hammerscale and provides analyses on the basis of ICP-OES (Inductively Coupled Plasma Optical Emission Spectroscopy) and SEM-EDAX (scanning electron microscopy with energy dispersive analyser. Magnetic susceptibility testing has also been undertaken. Statistical treatment of the data follows. **Section six** presents the MW typology/macro morphology and the SEM-EDAX results of the MW analysis. Finally **Section seven** provides statements re the site. References, Tables and Figures follow.

Table 1. Main metallurgical features

Type of features	**Context No**	**Dimensions/description**
pits	420BF	Oval BF; Sub-circular in plan, sides steeply sloped, base mostly flat; 0.44m wide x 0.13m deep
	424BF?	Sub-oval in plan, sides slope gradually, base nearly flat, small ledge at eastern end ; 0.75m x 0.50m x 0.12m deep
	426BH	Stepped Oval pit; 1.17m x 0.56m x 0.39m deep; slopped base/vertical sides; fills:494/493/492/425; ch/slag
	482	Sub-rectangular pit, N-S orientation, sides slope gradually, base is irregular. 0.40m x 1.50m x 0.15m deep
	437BF	Oval pit; 0.42m x 0.36m x 0.08m; flat base; gradual break of slope
	540BF	Circular in plan, sides steeply sloped, base flat; 0.40m wide x 0.08m deep
	561	Linear pit. Sides concave and steeply sloped, base concave. 0.40m x 0.19m deep
	608	Pit, sub-oval in plan. East side vertical others gently sloped, base irregular. 0.34m x 0.60m x 0.10m deep
	610BF	Circular pit; 0.84m x 0.74m x 0.12m; gradual sloping sides; flat base.
	616	Curvilinear gully/windbreak. Sides concave, base is flat. 0.53m x 3.80m x 0.13m deep
	861	Keyhole or figure of eight shape on plan, base is undulating and concave, getting deeper towards SE end. Sharp break of slope at top of cut, gradual break of slope at NE end, sharp at SW end; 2.49m x 0.31-0.97m wide x 0.29m deep

***Figure 1a: Killickaweeny archaeological site; after excavations by IAC LTD (Walsh 2003*).**

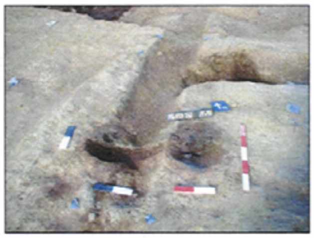


Plate 15: Possible bowl furnaces, from SW

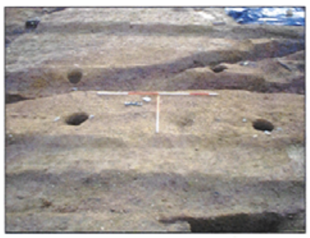


Plate 16: Structure D, from E

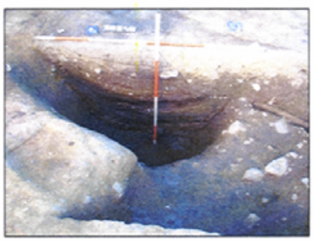


Plate 17: Pit **C364**, half section from W

Plate 18: Possible shaft furnace (**C861**) from E

Figure 1b: site photos of bowl furnaces C437 and C540, Structure D, pit C364 and feature C861 (after Walsh 2003)

2.0 Methodology

The methodology for the examination and characterisation of the MW and the metallurgically related features at KAY is outlined as follows:
Processing of the information given in the Data Structures Report (Walsh 2003) to include a list of features is given in Table 1 with their dimensions and main characteristics. A large number of samples were obtained to include soils, slags and hammerscale (the latter identified as such by the excavators). Soil samples were taken only from a number of contexts, particularly those associated with C364 and C861, but also some metallurgical features (see Table 2). A list with samples consisting of hammerscale is given in Table 6 and one for slags in Table 8. Slags are classified by context and their associated weights. Appendix A provides the dimensions of large and small pieces.

The methods of analysis and testing used in the examination of the metallurgical waste is outlined as follows:

- Typological/morphological characterisation of the IW
- ICP-AES analysis of soils, hammerscale and slag.
- SEM-EDAX analysis of the MW
- Magnetic susceptibility of soils and hammerscale (select contexts)
- Artefact analysis)

Chemical analysis of soils offers a potentially powerful tool for the characterisation of metallurgically-related features, i.e. those which in their fills/contents, not only show evidence for slag, charcoal, and/or metal residues but have actively participated in metalworking/making; in other words they have not merely served the purpose of refuse pits, or their "metallurgical identity" did not develop posthumously, i.e. as a result of abandonment and/or taphonomic conditions. To clearly characterise metallurgical and non-metallurgical features one needs a control set of data against which the "unknown" features can be tested. No such control group exists for KAY. In that light a statistical package is used to a) establish how well the three groups (soils, hammerscale and slag) separate and b) to introduce two additional sets of data, namely LOI (Loss on Ignition) and magnetic susceptibility values as a means of achieving further differentiation between soils from different features. The purpose of the exercise to be provide an independent means for feature characterisation on the basis of a combination of parameters which can be clearly calculated. There is, of course, plenty of scope for refinement of the technique and the excavators' cooperation and assistance in scrutinising the data to that end is paramount.

3.0 The natural resources

3.1 The ores

Bog iron ores are elusive in the archaeological record because of their regenerative nature (see below) and the fact that morphologically they 'blend' well with the spongy bloomery slags and weathered blooms.

Scott (1978) gives a map of the different types of deposits of iron ores across the country (Figure 2), to include laterites, hematites, pyrites and also bog ores. We suspect that the latter is more widespread than is currently assumed. Iron ores were worked in Ireland from the C16th until the early C20th Hematite veins and cherts of various ages were worked and also Carboniferous clay ironstone concretions and bands, particularly in coalfields in Leinster and Connacht, and also around the Shannon estuary. Laterites in County Antrim were last exploited in 1939-45 (Sevastopulo 1981, 288).

The primary supply of iron probably well into the second millennium AD was most likely bog ore, obtained during the cutting of peat for domestic fuel. Analyses of slag taken from the ring-fort at Cush in Co Limerick (O'Riordain 1940) and the rath at Mullaghbane, Co Tyrone (Harper 1972) and actual finds of ore at the settlement of Reask (Fanning 1981) support bog ore as the main source of iron in Ireland at that period (Mytum 1992, 229). On the other hand, ore may have also been mined, as was the case at the Garryduff I ring fort where surface outcrops of Yellow Sandstone or Lower Limestone Shale were available (O'Kelly 1962, 103) or even a combination of the two.

Bog iron ores are seepages leached out of the underlying iron-rich rock. Mineralogically they are non-crystalline iron oxyhydroxides of an average iron content of c. 30-40%. As such they are rich sources of iron ore. They are regenerative sources of iron, since they can reform at a considerable thickness over of a period of c. 30 years. Bog iron ores are only likely to be rich in silica if contaminated by quartz sand - windblown sand or sandstone debris. They can occur in association with manganese oxide nodules (Hall and Photos-Jones 1998; Photos-Jones *et al* 1998). The presence of high levels of manganese in nearly all the KEK-M4 sites' slags examined earlier certainly points to such a source for these sites (Photos-Jones 2003). The wide availability of bog ores, the fact that they can reform after a cycle of a few decades at "the same spot", their high iron content which together with the high manganese content acts as a flux, lowering the melting point of the slag, and finally the small amounts of phosphorus which can be absorbed in the metal, make them particularly useful for early bloomery technology and certainly the most favourite of all iron sources among farmers-smiths (Photos-Jones et al 1998).

In general, we can assume that bog iron ores occur around the margins of bogs and wetlands where the environment is wet, and iron can be leached out of the underlying rock. Bogs started to grow with climate change about 4500BP. This is a clue that the development of bog iron ores may have gone in parallel with the development of bogs during the last 4000 years or so.

The KAY slags do reflect bog ores not only on account of the manganese content but phosphorus as well; but the source of calcium, not seen in similar amounts in the KEK-M4 slags, needs to be investigated further. It may have derived from the fuel (particularly oak) but bone may have been an alternative source as well. (see below). Alternatively, a lime source can not be excluded.

3.2 Fuel Analysis from Metalworking Slag

Bloomery and early blast furnaces depended on large amounts of charcoal as fuel. At St Gobnet's round house at Ballyvourney, Co Cork, charcoal was found to be derived from, probably the coppicing of hazel, willow and poplar (O'Kelly 1952). On Church

Island, near Valencia, Co. Kerry where no local raw materials were actually available but had to be supplied from the mainland, about 250kg of charcoal were found in a round timber hut along with charcoal and slag within the bottom of a bowl furnace (Tylecote 1986, 187). KAY charcoal derived predominantly from ash, alder and hazel (see report by O'Carroll). The KEK-M4 sites produced evidence for oak (Rossan V) and hazel (Newcastle II and Johnstown I) (Photos-Jones 2003).

Oak which reacts well to coppicing has always been especially favoured for smelting (Tylecote 1962). It is possible that hazel charcoal recovered from the Newcastle II site was originally from the wood kindling, as hazel is not one of the best charcoal types for smelting, but has been favoured as a kindling fuel for many purposes in the past, including bakery ovens (Edlin 1973, p158). Alternatively, it may also reflect the casual use of whatever timber was locally available for smelting. Since hazel has a long association with construction in Ireland, and was managed extensively to provide rods for wattle purposes throughout Irish history, it appears likely that this resource would have been available in abundance.

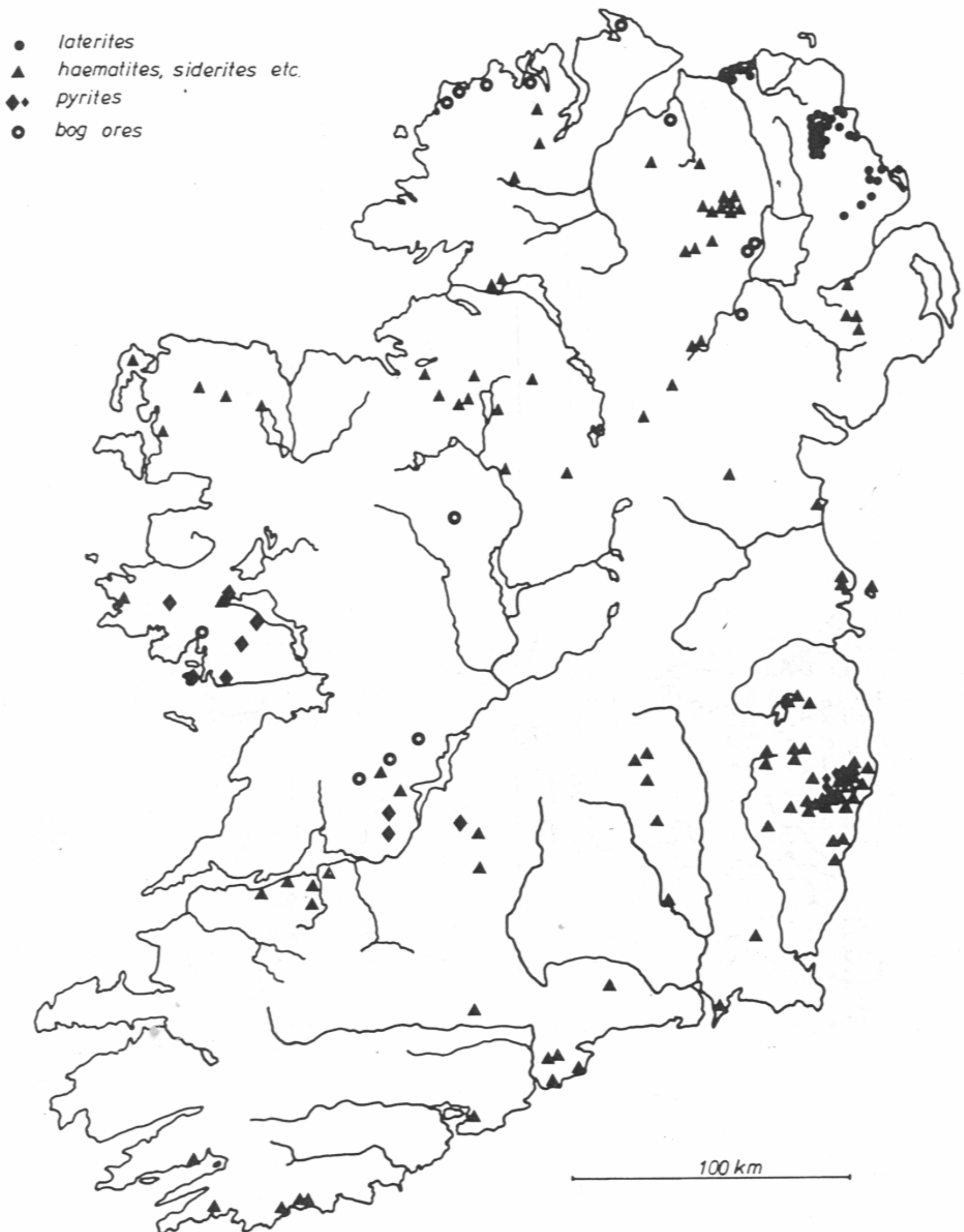


FIG. 7 — Distribution of the main iron ore sources in Ireland.

19

Figure 2: Distribution of the main iron ore sources in Ireland (Scott 1978)

4.0 The Bloomery

4.1 Bloomery Iron making in Ireland: a brief review

The middle of the first millennium BC is characterised in Ireland by the decline in the use of bronze as the primary metal. Iron appears to substitute bronze but the archaeological record is richer in artefacts rather than in metal-working sites. In short, there exists little evidence for iron-making and working activities in the period from 500 BC to the first few centuries AD which suggests either that a large number of these artefacts may have been imported or that contemporary sites may have been overlooked on account of a general shortage of C-14 dates. Recently however, the technological examination of finds from sites along the KEK-M4 motorway revealed a number of early dates, namely second half of the first millennium BC) (see Photos-Jones, 2003a) with clear evidence for iron making. Needless to say the importance of these sites is fundamental to our understanding of the introduction of iron in Ireland. from the sixth century AD onwards, there is a dramatic increase in the use of iron, as can be manifested both by the wide range of artefacts found on Early Medieval sites as well as the number of iron working sites.

Major iron-working centres are evident in the archaeological record, for example Ballyvourney (O'Kelly 1952), Clogher (Scott 1983), where the forge is located in one of the fort ditches, or the ecclesiastical centre on Church Island, Co Kerry (O'Kelly 1958), where smelting and smithing activities are evident despite the lack of an iron ore supply on the island. Mytum (1992) suggests that many people were using basic iron technology to make and repair simple artefacts but that complex iron artefacts were still being produced by specialised smiths.

Smelting of iron ore was undertaken in a simple bowl furnace; although it is assumed that these furnaces were often not well preserved, it has been suggested that they could have been low shaft furnaces (Tylecote 1986). In the case of furnaces like those from the KEK-M4 sites, it is certain that they never had a shaft. Small pits, such as those found at the ring-fort Garryduff I, were lined with clay into which the charcoal and iron ore would be placed (O'Kelly 1962). The slag was not tapped but formed in the bottom of the furnace, along with the charcoal while the metallic iron was left to form a bloom. At Ballyvourney in Co. Cork, a major iron production site from the 6th to 13th century AD, not only was heavy furnace bottom slag found but also glassy slag produced by slag tapped out of the pits and not solidifying at the bottom of the furnace (O'Kelly 1952). Also at Ballyvourney a fragment of a tuyere was discovered. These tuyere fragments which can be characterised either as blow holes or as tuyere proper are found in many sites including of KAY (see Figure 1c).

Figure 1c
Photo of tuyere (02E1002:395:1) (after Moraghan 2003)

Smelting slag was evident at various sites during the Early Medieval period. These included ring forts like Ballycatten (slag was found in a black deposit dated to around 600AD), or Garranes, Co. Cork (O'Riordain and Hartnett 1943) but also monastic centres such as Laithmore, Tipperary dating to the 7th century (Tylecote 1986, 188). Later sites include Lagore Crannog, which appears to have made a move from decorative bronze working in the 7th century AD to iron weaponry after the Norse invasion (Tylecote 1986, 188). Evidence of iron smelting in the form of a bowl furnace, bottom slag and glassy slag as well as possible indication of smithing activities (described below) are all dated to two phases of occupation from the 8th – 11th century AD (Hencken 1950).

Primary (smelting) and secondary (smithing) activities are rather difficult to differentiate when the only evidence available is slag. As Edwards (1996) notes in past excavations the slag was either not recorded systematically or rarely analysed to provide additional information about the activity that generated it. At Lagore crannog there is evidence for an iron working floor. Several hearths were located together and a sufficient amount of particles of free magnetic iron and iron oxide were recovered to suggest iron working (Hencken 1950, 233). However, magnetic residues are not indicators of smithing only but smelting as well. Furthermore, unless properly sorted, they may point only to heated soils with no particular relevance to metalworking.

Problems of nomenclature can also arise particularly when comparing data from older publications. Thus pits and hearths and post holes may be terms which can potentially be defined differently by different excavators

The use of the bloomery process continued throughout the medieval period into the post-medieval period. The same evidence for smelting and smithing is evident in various medieval sites both rural and urban. At Ballyman, a 14th century iron-working area with associated living area near the church of Glen Murieri, Co. Dublin, the bottom of a bowl furnace was found along with furnace bottom, glassy slag and charcoal (Young et al 1986). A possible anvil stone covered in charcoal and slag dust supports smithing activities on site also. In the settlement at Coney Island, Lough Neagh similar finds were made to suggest that the community had established its own iron industry (Addyman 1965).

The introduction of the charcoal operated blast furnace to Ireland in the 17th century, appears to be contemporary with that in Scotland/N. England. The presence of English ironmasters and/or settlers interested in industrialising the local iron industry and exploiting the country’s natural resources is as much in evidence as in Scotland. Ironworks were established on Sir Walter Raleigh’s estates in County Waterford earlier than the 1600s but were overrun by the Irish in 1598 and the town burnt to the ground (Schubert 1957, 189). Similar type of enmities were also recorded in Scotland and it appears that the imposition “from above” of foreign practices on a population well versed in its own way of making iron could only be to the detriment of foreign enterprises. In the early 1600s ironworks many ironworks were established, one of the most profitable partnerships was Richard Boyle and Charles Coot who controlled the largest number of works, for example the furnaces at Cappoquin on the river Black-water built in 1625 (Schubert 1957,190). Industrial development in Ireland however was seriously hindered by the 1641 rebellion when the Irish destroyed all the ironworks and although the iron industry emerged again after this period it never regained the momentum and prosperity of the first few decades of the 17th century. Throughout this period it would appear that the native Irish were still employing the bloomery process in parallel with the more advanced technology of the blast furnace

4.2 About bloomery iron making in general

In the bloomery, metallic iron was reduced from its ore while in the solid state, i.e. the iron was never intentionally molten. The numerous slag impurities trapped within the bloom had therefore to be hammered out resulting in a billet that was subsequently shaped or forged into the desired artefact. It is these slag inclusions detected within the metal artefact that a) bear testimony to the bloomery process and b) provenance the source of the raw material (i.e. the type of ore). As part of a later phase of work, slag inclusion analysis on metal artefacts (two) from KAY was undertaken for the purpose of matching slag with artefact. There is little doubt that the majority of the artefacts found on site would have been made locally, hence the need to have technical analysis of the iron used to characterise the type of metal produced, (low carbon /high carbon or phosphoric).

Bloomery slags have been traditionally classified as “tapped” and “non-tapped” on the basis of the method of their removal in the course of the smelting operation. When tapped they acquire the characteristic drop-like surface texture. When non-tapped they tend to accumulate around the bloom and/or drip from it, ending up as small/large lumps at the furnace floor or when the smelt has been largely unsuccessful, as furnace bottoms. The space allocated for the bloom to form is of course a function of the distance of the tuyere from the furnace floor.

Smelting and smithing slags have been traditionally differentiated on the basis of their morphology, primarily the presence or absence of smithing hearth bottoms, but this is at best a first level classification. Chemically slags of the smelting or smithing type are iron-rich (with up to 60-70% iron oxide), crystalline, spongy, dense and brown-black in colour. Such high percentages of iron in the waste product, testify to the inherent inefficiency of the bloomery and the urgency that must have been felt by the iron masters of the 13th/14th AD century to convert first to water powered bloomeries which would have increased yields but not necessarily efficiency and second to the blast furnace which would have resulted in good separation between slag and metal. Mineralogically, smelting and smithing slags tend to be similar, but it is on the basis of characteristic fingerprinting elements that a distinction between the two processes, primary and secondary can be achieved. However, in the absence of fingerprinting elements there is little chance for a conclusive statement to be made unless there is associated evidence like metallurgical ceramics such as fragments of tuyeres, furnace wall or lining, hearth walls and similar ancillary evidence**. For most primitive bloomeries it is assumed that smelting and smithing would be taking place side by side, and this is certainly the case at KAY.**

5.0 Archaeological Materials

A number of samples to include soils, hammerscale and metallurgical waste have been subjected to chemical analyses and magnetic susceptibility testing.

5.1 The Soils

5.1 .1 The soils of pit/cistern C364 (in purple), of furnace C861 (in turquoise), others (C426, C436, C539) (in green); background (in grey)

Table 2 below gives a list of soil samples (as per SASAA nos) analysed by ICP–AES and tested for magnetic susceptibility; their contexts/sample numbers (as per IAC nos) are also included together with a set of seven samples representing natural, the control group.

Table 2: Soil Samples and their contexts/samples

SAE No.	Context	Sample	Feature
SAE 23.25	3	3	Natural
SAE 23.24	3	5	Natural
SAE 23.23	3	3	Natural
SAE 23.22	3	2	Natural
SAE 23.21	3	6	Natural
SAE 23.20	3	4	Natural
SAE 23.3	363	607	Fill of C364 large deep pit, poss. cistern

SAE 23.4	363	611	Dtt
SAE23.27	363	659	Dtt
SAE23.28	363	601	Dtt
SAE 23.10 (1-3)	389	654	Dtt
SAE 23.11 (1-3)	390	655	Dtt
SAE 23.9 (1-3)	391	656	Dtt
SAE 23.8 (1-3)	392	657	Dtt
SAE 23.7 (1-3)	393	658/600	Dtt
SAE 23.19 (1-3)	395	752	Dtt
SAE 23.15	397	765	Dtt
SAE 23.16	397	741	Dtt
SAE 23.1	42	503	Fill of Ditch A,
SAE 23.2	425	512	Fill of feature 426, bowl furnace+hearth?
SAE 23.5	436	623	Fill of feature 437, bowl furnace
SAE 23.6	539	627	Fill of feature 540, bowl furnace
SAE 23.17	88	1159	Fill of Feature C22
SAE 23.13	889	1160	Fill of Feature C861
SAE 23.12 (1-9)	890	1165	Dtt
SAE 23.14	891	1170	Dtt
SAE 23.26	937	1184	Dtt
SAE 23.18	965	1185	Dtt

Soil samples were analysed for thirty two elements by ICP-AES (see Table 3). The concentrations of the major elements are expressed in weight per cent of the element as an oxide, while those of the trace elements in parts per million. ICP-AES analysis results show that soils are primarily rich in silica (65-75% SiO_2), about 6-8% Al_2O_3 (clays), 3-5 % FeO and less than 1% CaO. For the samples which are rich in iron like 23.28 (C392), 23.2 and 23.1 (C425) as well as 23.12 (C890), it is clear that due to the metallurgical nature of these features, slag and iron-rich magnetic residues must make up the soil content and therefore are high in iron. Data for hammerscale and slags are also included in Table 3 (see below).

5.1.2 Magnetic Susceptibility of soils of pit/cistern C364, of furnace C861, others (C426, C436, C539); background (in grey)

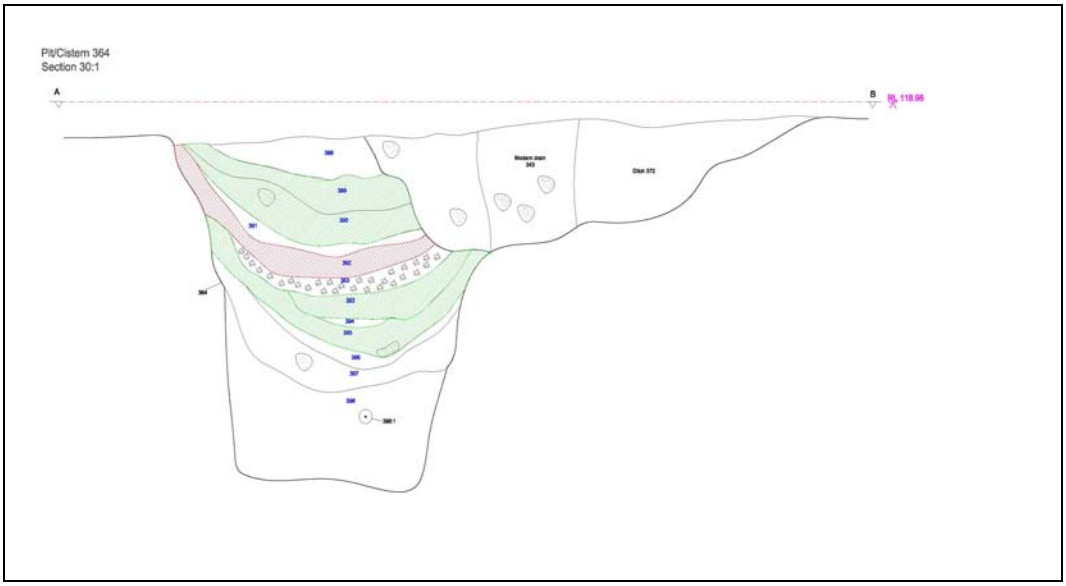
Magnetic susceptibility testing is a means of assisting in the elucidation of the metallurgical nature of the contents of different features**.** The results are presented in Table 4. Only a small number of samples gave mag susc results above natural and these are highlighted in red.

From Table 4, it is concluded that the nature of the feature C364, said to be the cistern, is not metallurgical while C861 said to be the furnace is most likely metallurgical. Figure 3a shows the contexts within C364 which have high mag susc values (in red) and the corresponding layers within C861 in Figure 3b. It is likely that the latter rather than being a furnace, the feature must have served as a bloom smithing /iron working hearth. Feature 437 (fill C436) and feature C540 (fill C539) are both regular bowl furnaces of the type seen along the other KEK-M4 scheme sites; Feature 426 (with fill C425), a stepped bowl furnace, may be a combined hearth and bowl or a bowl with well-outlined space for bellows and working area.

Table 4: Soil Samples, their contexts and magnetic susceptibility measurements

SASAA No	Context	Feature	Mag. Susc
23.01 ms (1/1)	42	Fill of Ditch A	800.9
23.10 ms (1/3)	389/654		47.8
23.10 ms (2/3)	389/654	cistern	41.9
23.10 ms (3/3)	389/654		39.9
23.11 ms (1/3)	390/655		29.3
23.11 ms (2/3)	390/655		33.2
23.11 ms (3/3)	390/655		32.1
23.12 ms (1/9)	890/1165	furnace	577.8
23.12 ms (2/9)	890/1165	furnace	1276.7
23.12 ms (3/9)	890/1165	furnace	559.8
23.12 ms (4/9)	890/1165	furnace	1044.4
23.12 ms (5/9)	890/1165	furnace	805.1
23.12 ms (6/9)	890/1165	furnace	950.8
23.12 ms (7/9)	890/1165	furnace	729
23.12 ms (8/9)	890/1165	furnace	1262.1
23.12 ms (9/9)	890/1165	furnace	674.9
23.13 ms (1/1)	890/1165	furnace	26.6
23.14 ms (1/1)	890/1165	furnace	28.6
23.15 ms (1/1)	890/1165	furnace	3.1
23.16 ms (1/1)	397/741		3.6
23.17 ms (1/1)	88/1159	C22	246.9
23.18 ms (1/1)	965/1185	furnace	27.5
23.19 ms (1/3)	395/752		30.5
23.19 ms (2/2)	395/752		190.2
23.19 ms (3/3)	395/752		52.8
23.02 ms(1/1)	425/512	Bowl furnace	1121.3
23.20 ms(1/1)	natural		1.5
23.21 ms(1/1)	natural		6.6
23.22 ms(1/1)	natural		10.6
23.23 ms(1/1)	natural		6.1
23.24 ms(1/1)	natural		6.2

SASAA No	Context	Feature	Mag. Susc
23.25 ms(1/1)	natural		13.3
23.26 ms(1/1)	937/1184	furnace	130.8
23.27 ms(1/1)	363/659	cistern	258.6
23.28 ms(1/1)	363/601		273.2
23.03 ms(1/1)	363/607		244.4
23.04 ms(1/1)	363/611		300.7
23.05 ms(1/1)	436/623	Bowl furnace	2889.6
23.06 ms(1/1)	539/627	Bowl furnace	2179.2
23.07 ms (1/3)	393/658/600	cistern	14.7
23.07 ms (2/3)	393/658/600		15.3
23.07 ms (3/3)	393/658/600		13.2
23.08 ms (1/3)	392/657		85.1
23.08 ms (2/3)	392/657		920
23.08 ms (3/3)	392/657		94.4
23.09 ms (1/3)	391/656		31.9
23.09 ms (2/3)	391/656		33.9
23.09 ms (3/3)			36.6
Standard 3			241.1
Standard 4			240.4



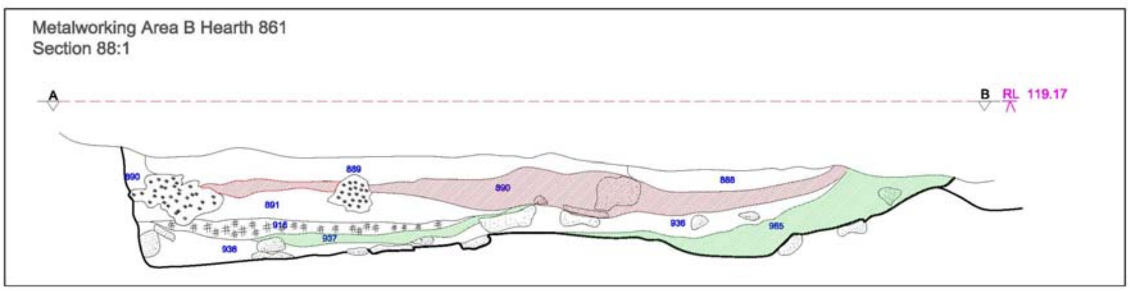


Figure 3a (top): Feature C364 showing areas/contexts for which magnetic susceptibility is high (in red; C392) and areas/contexts for which it is low (in green; C389, C390, C393 and C395). Only one context /horizon is relatively high in mag susc.(C392) probably deriving from the dumping of a band of metallurgical waste or simply waste which has been heated within.

Figure 3b (bottom): Feature C861 showing areas/contexts for which magnetic susceptibility is high (in red; C890) and areas/contexts for which it is low (in green; C937 and C965). C861 is most likely a hearth.

5.1.3 LOI of soils of cistern C364, of furnace C861 others (C426, C436, C539); background (in grey).

Table 5: Soil Samples, their contexts and LOI in percent weight.

Loss on ignition					
Sae No.	Sample g.	LOI 500C	%	LOI 950C	%
SAE 23.10 (1/3)	0.86	0.798	7.2	0.7783	9.5
SAE 23.17	0.6893	0.6379	4.6	0.6313	8.4
SAE 23.18	0.44	0.4179	5	0.4134	6
SAE 23.14	0.6799	0.6537	3.9	0.6485	4.6
SAE 23.12 (3/9)	0.4222	0.3571	15.4	0.348	17.6
SAE 23.9 (1/3)	0.5116	0.4666	8.8	0.4503	12
SAE 23.15	0.6099	0.5751	5.7	0.5321	12.76
SAE 23.10 (3/3)	0.5584	0.5209	6.7	0.5057	9.4
SAE 23.10	0.475	0.4565	3.9	0.4179	12.02
SAE 23.12 (1/9)	0.4669	0.3762	19.4	0.3621	22.4
SAE 23.19 (3/3)	0.429	0.3883	9.5	0.3797	11.5
SAE 23.26	0.5321	0.5098	4.2	0.4707	11.5
SAE 23.20	0.5096	0.4844	4.9	0.4803	5.7
SAE 23.21	0.461	0.4398	4.6	0.4355	5.6
SAE 23.22	0.5038	0.4818	4.4	0.4782	5.1
SAE 23.28	0.44	0.3524	19.9	0.3441	21.8
SAE 23.24	0.4353	0.4118	5.4	0.4075	6.4
SAE 23.2	0.4997	0.4391	12.1	0.4302	13.9
SAE 23.25	0.5175	0.4962	4.1	0.4905	5.2
SAE 23.13	0.5545	0.5333	3.8	0.5293	4.5
SAE 23.10	0.5306	0.3865	27.2	0.381	28.2
SAE 23.7 (3/3)	0.4845	4613	4.8	0.4333	10.6
SAE 23.12 (8/9)	0.3835	0.2983	22.2	0.2898	24.4
SAE 23.12 (7/9)	0.5038	0.4027	20.1	0.3925	22.1
SAE 23.12 (2/9)	0.4446	0.3588	19.3	0.3458	22.2
SAE 23.12 (4/9)	0.5329	0.4194	21.3	0.406	23.8
SAE 23.12 (6/9)	0.4386	0.3373	23.1	0.3269	25.5
SAE 23.12 (9/9)	0.3908	0.3162	19.1	0.3073	21.4
SAE 23.12 (3/3)	0.4983	0.4792	3.8	0.4539	8.9
SAE 23.12 (S/9)	0.4378	0.4453	3.8	0.4142	18.7
SAE 23.7 (3/3)	0.463	0.4453	3.8	0.4142	10.5
SAE 23.8 (1/3)	0.47	0.4339	7.7	0.4175	11.2
SAE 23.5	0.48	0.4054	15.5	0.3931	18.1
SAE 23.4	0.6048	0.3544	18.5	0.3438	20.9
SAE 2.7 (1/3)	0.42	0.4007	4.6	0.3761	10.5
SAE 23.8 (2/3)	0.4711	0.4297	8.8	0.4168	11.5
SAE 23.11 (3/3)	0.544	0.5095	6.2	0.4883	10.1

A varying amount of organic material, moisture and carbonates is included in the samples analysed. This amount varies from c.5% (the natural) to c. 30% (sample 23.10). When the LOI values (heating at 950C) are plotted (percentage vs. frequency) (see Figure 4) they separate around two peaks: one around 11% and the other around 21%. Is it perhaps worth investigating further whether the soils in the two groups can be differentiated on other grounds as well (texture, colour etc).

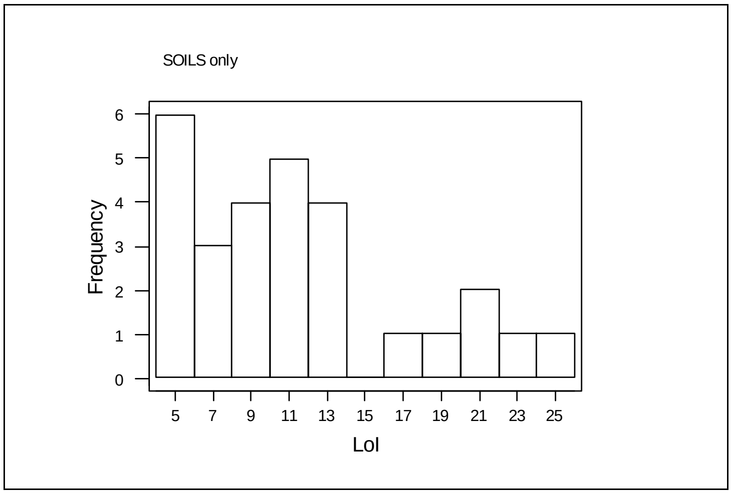


Figure 4: Plot of LOI values (heating at 950C) versus frequency (how many samples have LOI values ranging between 7 and 8 or 8 and 9 etc. data cluster around two peaks: one around 11% and the other around 21%.

5.2 The Hammerscale

5.2.1 The samples and how to characterise them

Materials suspected as hammerscale have been collected from a large number of contexts during the sieving programme by I.A.C., see Table below. Hammerscale "travels" well around the site just like fragments of charcoal. As a result, not all contexts in which it is found, can be thought of as metallurgical in origin. For example some contexts within the cistern may contain hammerscale but they do not make the cistern metallurgical in function. Since the purpose of this investigation is to characterise both the material and the feature from which it derives, in theory and should plentiful of funds were made available, each individual bag labelled hammerscale should be subjected to XRD analysis. The purpose of the exercise would be to ascertain whether the contents of the bag were rich in magnetite, hematite, wustite or fayalite as opposed to heated ferrugenous soils. Table 3 of ICP-AES data suggests that the bulk chemical composition of hammerscale falls –as expected – between soils and slags, with silica (30-35% SiO_2), about 3-4% Al_2O_3 (clays) and 40-45 % FeO; CaO is less than 1% CaO. Of the samples analysed 23.355 (C673), is more likely to be a ferruginous soil.

Table 6: Samples suspected of containing hammerscale and, their contexts

SASAA No	Context	Sample	Comments
23.362	120	248/346/247/435	Rectilinear feature C27
23.300	221	251/252/253	Square pit C5
23.301	222	222/258/257	Square pit C5
23.314	362	415	pit C361
23.306	365	416/422	pit C359
23.307	382	468/469	pit C383
23.310	388	535	Cistern
23.357	389	654/536	Cistern
23.358	390	655/539	Cistern
23.312	391	656/553/538	Cistern
23.311	392	657	Cistern
23.309	393	602/578/658	Cistern
23.359	394	660/618/606/604	Cistern
23.356	395	752/739	Cistern
23.313	396	764/740	Cistern
23.304	425	619	Ind. Feature, C426
23.303	438	719	Ind. Feature, C556
23.308	499	710	Cistern
23.364	550	634	C437 Bowl furnace
23.361	551	635	C540 Bowl furnace
23.346	632	947	Structure B
23.343	633	951/950	Structure B
23.352	634	956	Structure B
23.365	640	720	C556 windbreak?
23.363	643	744/783	Structure B posthole C456
23.367	656	821	C610 Bowl furnace
23.330	660	946/911	Structure B
23.332	664	851/825	Structure B
23.333	669	831/832	Structure B
23.348	670	830	Structure B
23.344	672	837	Structure B
23.355	673	858	Structure B
23.353	674	952	Structure B
23.354	675	916	C502 windbreak?
23.350	685	835	C608 metallurgical pit
23.349	687	840	Structure B

23.347	690	889	Structure B
23.351	691	850	Structure B
23.305	692	860	Ind. Feature C616 windbreak?
23.331	695	886/877	Structure B
23.366	696	876	C616 windbreak?
23.339	703	887	Structure B
23.334	705	914	Structure B
23.340	706	913	Structure B
23.327	708	910	Structure B
23.326	712	918	Structure B
23.341	715	919	Structure B
23.325	733	944	Structure B
23.335	734	949	Structure B
23.302	740	957	Square pit C616 windbreak?
23.316	756	958/971	Structure B
23.322	760	972/975	Structure B
23.321	761	974	Structure B
23.323	782	1007/1081	Structure B
23.317	783	1008/1015	Structure B
23.319	784	1009/1028/1026	Structure B
23.337	785	1039	Structure B
23.320	786	1042/1040	Structure B
23.338	787	1041	Structure B
23.324	791	1014/1029	Structure B
23.342	792	1013	Structure B
23.315	793	1010	Structure B
23.318	794	1025	Structure B
23.329	802	1023	Structure B
23.345	822	1017	Structure B
23.336	834	1019	Structure B
23.328	852	1043	Structure B

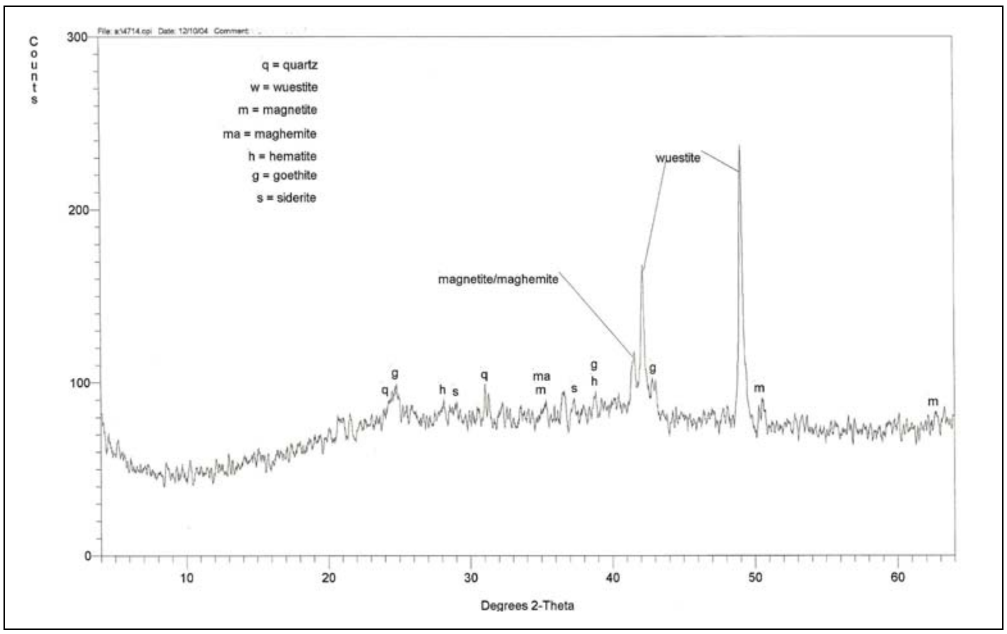


Figure 5: XRD results for sample 23.345

5.2.2 The magnetic susceptibility of hammerscale

Table 7 shows that hammerscale is characterised by high mag susc results. Of Apart from features C426 and C 437, the metallurgical role of three more shown below needs to be investigated further. These include C616 and C608 and C460.

Table 7: Hammerscale samples, their contexts and magnetic susceptibilit results

SAE No.	Mag. Sus	Description of context
Standard 2	240.7	
23.302 HA/MS	3969.6	C740 fill of C616
23.303 HA/MS	4860.5	C438 fill of C556
23.304 HA/MS	3561.2	C425 fill of C426
23.305 HA/MS	4527.5	C692 fill of C616
23.308 HA/MS	3939.1	C499 fill of C364
23.311 HA/MS	3466.3	C392 fill of C364
23.349 HA/MS	5294.6	C687 fill of C608
23.355 HA/MS	6877.5	C673 fill of C460

5.3 Metallurgical waste: Slags

5.3.1 Typological Investigation

The industrial waste from a large number of contexts has been examined. The samples have been weighed and measured along the long axis only (see Table below). Fines were also weighed. When large ‘fragments’ were encountered, all dimensions (and not simply the long axis) were recorded (see Appendix A). The total weight was c. 86 kg.

Table 8: Slags, their contexts and weights.

SASAA No	Context	Weight
23.41/SL		
23.50/SL	120	5207
23.51/SL	393	2254
23.52/SL	390	1410
23.53/SL	363	3729
23.54/SL	425	1817
23.55/SL	891	970
23.56/SL	890	
23.57/SL	499	5121
23.58/SL	890	9035
23.59/SL	363	402
23.60/SL	916	121
23.61/SL	719	275
23.62/SL	3	816
23.63/SL	889	3979
23.64/SL	642	66
23.65/SL	889	515
23.66/SL	395	124
23.67/SL	509	118
23.68/SL	120	21
23.69/SL	438	116
23.70/SL	890	52
23.71/SL	654	438
23.72/SL	740	803
23.73/SL	560	367
23.74/SL	562	311
23.75/SL	648	383
23.76/SL	654	37
23.77/SL	734	264
23.78/SL	703	38
23.79/SL	695	3
23.80/SL	634	14
23.81/SL	380	44
23.82/SL	613	2684
23.83/SL	786	63
23.84/SL	712	40
23.85/SL	246	139
23.86/SL	633	392
23.87/SL	715	56
23.88/SL	581	771
23.89/SL	664	466
23.90/SL	715	182
23.91/SL	692	786
23.92/SL	761	41
23.93/SL	635	
23.94/SL	698	17
23.95/SL	612	1025
23.96/SL	712	472
23.97/SL	60	
23.98/SL	696	293
23.99/SL	621	646
23.100/SL	791	289
23.101/SL	821	244
23.102/SL	792	12
23.103/SL	859	28
23.104/SL	783	17
23.105/SL	785	17
23.106/SL	646	68
23.107/SL	692	504
23.108/SL	562	263
23.109/SL	560	405
23.110/SL	425	3860
23.111/SL	376	75
23.112/SL	340	58
23.113/SL	685	16
23.114/SL	570	27
23.115/SL	2	13
23.116/SL	42	457
23.117/SL	563	285
23.118/SL	612	360
23.119/SL	395	123
23.120/SL	425	67
23.121/SL	506	26
23.122/SL	339	10
23.123/SL	363	122
23.124/SL	438	532
23.125/SL	425	2012
23.126/SL	234	505
23.127/SL	619	697
23.128/SL	480	459
23.129/SL	42	322
23.130/SL	615	159
23.131/SL	58	98
23.132/SL	480	1673
23.133/SL	656	147
23.134/SL	438	195
23.135/SL	590	618
23.136/SL	42	983
23.137/SL	58	743
23.138/SL	564	878
23.139/S/	644	77
23.140/SL	47	3
23.141/SL	35	7
23.142/SL	154	1

23.143/SL	393	10
23.144/SL	392	24
23.145/SL	425	37
23.146/SL	784	2
23.147/SL	673	5
23.148/SL	664	284
23.149/SL	58	192
23.150/SL	380	8
23.151/SL	746	55
23.152/SL	689	37
23.153/SL	377	19
23.154/SL	380	74
23.155/SL	222	10
23.156/SL	276	
23.157/SL	746	53
23.158/SL	687	2
23.159/SL	617	133
23.160/SL	660	24
23.161/SL	695	32
23.162/SL	260	11
23.163/SL	783	264
23.164/SL	665	42
23.165/SL	539	81
23.166/SL	434	53
23.167/SL	120	18
23.168/SL	260	34
23.169/SL	756	6
23.170/SL	542	20
23.171/SL	436	31
23.172/SL	195	52
23.173/SL	13	121
23.174/SL	478	96
23.175/SL	58	2440
23.176/SL	692	765
23.178/SL	786	251
23.179/SL	706	94
23.180/SL	120	146
23.181/SL	546	778
23.182/SL	398	105
	363	
23.184/SL	673	114
23.185/SL	439	312
23.186/SL	699	2360
23.187/SL	490	113
23.188/SL	42	130
23.189/SL	63	678
23.190/SL	665	18
23.191/SL	560	77
23.192/SL	520	300

23.193/SL	389	649
23.194/SL	391	537
23.195/SL	660	32
23.196/SL	253	105
23.197/SL	696	156
23.198/SL	545	21
23.199/SL	120	5
23.200/SL	562	463
23.201/SL	438	736
23.202/SL	434	3158
23.203/SL	376	222
23.204/SL	489	12
23.205/SL	120	4
23.206/SL	478	14
23.207/SL	423	870
23.208/SL	364	2106
23.209/SL	375	744
23.210/SL	691	280
23.211/SL	2	15
TOTAL		**85945**

Table 8a. Contexts with low (0-100grams) (green), medium (101-499grams) (yellow) and high (500-9000grams) (red) amounts of slag.

Context	Slag Weights (grams)
154	1
687	2
784	2
47	3
756	6
35	7
222	10
339	10
489	12
792	12
634	14
685	16
698	17
785	17
377	19
542	20
545	21
392	24
506	26
570	27
2	28
859	28
436	31
695	35
689	37
703	38
761	41
260	45
195	52
660	56
340	58
665	60
642	66
646	68
644	77
539	81
706	94
253	105
398	105
746	108
478	110
490	113
509	118
673	119
13	121
916	121
380	126
617	133
246	139
656	147
615	159
715	238
821	244
395	247
734	264
719	275
691	280
783	281
563	285
791	289
376	297
520	300
439	312
786	314
648	383
633	392
696	449
654	475
234	505
712	512
391	537
590	618
621	646
389	649
63	678
619	697
375	744
664	750
581	771
546	778
740	803
3	816
560	849
423	870
564	878
891	970
562	1037
612	1385
390	1410
438	1579
42	1892
692	2055
364	2106
480	2132
393	2264
699	2360
613	2684

434	3211
58	3473
363	4253
889	4494
499	5121

120	5401
425	7793
890	9087

Table 3. of ICP-AES data suggests that the bulk chemical composition of slag is –as expected – silica (25-35% SiO_2), about 3-5% Al_2O_3 (clays) and 55-70 % Fe_2O_3; CaO is 5-10%. Of the samples analysed 23.59 (C363), is more likely to be a ferruginous soil. The source of CaO and its association with phosphorus is the subject of an investigation (see below) since calcium is unlikely to derive from the bog ore. Its source is the fuel or possibly bone.

Table 3: ICP-AES

ICP-AES analyses for KAY soils, slags and hammerscale; composition of oxides in weight %, metals in ppm.

		SiO2	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	TiO2	P2O5	MnO	Ba	Co	Cr	Cu	Li	Ni	Sc	Sr	V	Y	Zn	Zr	La	Ce	Nd	Sm	Eu	Dy	Yb	Pb
23.1		65.25	6.33	10.77	0.40	1.38	0.42	0.85	0.33	1.00	0.68	438	21	46	191	35	66	7	123	81	23	181	143	22	39	26	3.7	1.0	5.6	1.9	16
23.10	**1/3**	75.21	7.07	3.62	0.49	3.41	0.52	1.05	0.34	0.72	0.26	319	9	56	59	37	56	8	136	76	27	208	178	24	40	27	4.0	0.9	4.2	2.0	16
23.10	**2/3**	74.87	6.96	3.50	0.47	3.28	0.51	1.03	0.33	0.68	0.25	307	9	54	56	35	54	7	134	74	27	201	184	23	42	25	3.2	0.9	4.1	1.9	15
23.10	**3/3**	74.85	7.09	3.65	0.48	3.16	0.50	1.04	0.32	0.73	0.27	321	10	55	56	36	57	8	134	79	28	209	172	23	40	26	4.3	0.9	4.5	2.0	18
23.11	**1/3**	72.63	7.06	3.72	0.50	4.91	0.50	1.06	0.33	0.69	0.37	329	12	53	46	36	61	8	153	79	29	200	157	24	41	27	4.1	0.9	5.2	1.9	19
23.11	**2/3**	71.97	7.40	4.00	0.53	5.60	0.54	1.11	0.33	0.70	0.41	335	12	55	48	36	62	8	164	81	29	204	169	24	40	27	3.5	1.0	5.1	2.0	19
23.11	**3/3**	72.28	6.78	3.56	0.49	5.13	0.48	1.00	0.32	0.65	0.34	307	12	53	43	34	56	7	150	76	27	188	149	24	39	27	3.9	0.9	4.8	1.8	18
23.12	**4/9**	50.28	7.24	13.67	0.53	2.96	0.30	0.95	0.28	0.53	0.42	339	18	58	61	42	74	8	134	102	33	212	123	22	36	26	3.9	1.2	5.8	2.4	19
23.12	**8/9**	45.16	7.68	17.21	0.55	3.26	0.28	0.97	0.29	0.67	0.49	375	21	61	62	46	70	9	140	115	34	226	100	23	38	27	3.6	1.4	5.7	2.5	18
23.13		83.76	6.48	3.21	0.43	0.44	0.57	1.03	0.36	0.14	0.25	253	13	50	24	32	51	7	86	69	21	142	445	21	43	23	2.4	0.7	3.5	1.7	15
23.14		84.46	6.09	3.28	0.38	0.46	0.57	0.93	0.42	0.13	0.21	250	12	51	18	29	39	6	89	65	15	118	207	21	44	23	3.2	0.7	3.0	1.4	15
23.15		66.46	7.39	2.14	0.58	7.74	0.43	1.18	0.40	0.20	0.03	229	9	59	41	36	58	8	176	84	27	153	139	24	41	26	4.2	0.9	3.3	1.9	16
23.16		66.43	7.24	2.64	0.58	9.15	0.44	1.19	0.39	0.20	0.06	213	10	59	39	35	63	8	199	86	29	126	131	24	43	26	4.0	0.9	3.6	1.9	18
23.17		77.42	6.74	5.20	0.44	0.85	0.50	0.95	0.41	0.28	0.30	268	12	54	28	36	48	7	91	76	24	152	171	22	43	24	2.7	0.8	3.9	1.8	15
23.18		80.19	7.25	4.06	0.61	0.74	0.47	1.16	0.42	0.19	0.24	234	15	68	38	32	96	9	97	94	38	160	155	28	46	31	5.0	1.2	5.3	2.6	19
23.19	**1/3**	72.89	6.71	2.11	0.48	3.97	0.47	1.01	0.38	0.30	0.07	231	5	55	49	37	44	7	134	70	27	182	129	23	42	25	3.3	0.8	3.4	1.8	14
23.19	**3/3**	74.17	6.48	1.88	0.45	3.19	0.48	0.97	0.38	0.27	0.05	221	4	54	49	36	40	7	123	67	26	183	183	23	37	25	2.6	0.8	3.3	1.7	15
23.2		61.78	6.01	12.93	0.39	1.50	0.37	0.80	0.32	1.02	0.77	446	21	44	249	35	68	6	121	79	24	165	144	19	35	23	2.9	1.0	5.7	2.0	19
23.20		77.54	9.18	4.35	0.66	0.42	0.43	1.41	0.42	0.15	0.17	258	15	76	51	39	99	11	88	119	39	151	136	30	51	33	6.0	1.3	5.2	2.8	18
23.21		80.48	7.64	4.01	0.57	0.34	0.41	1.05	0.39	0.08	0.19	191	13	72	35	35	82	10	91	95	40	178	145	29	51	33	6.0	1.3	5.8	2.9	23
23.22		81.50	7.16	4.08	0.59	0.34	0.43	1.16	0.41	0.17	0.21	209	14	72	41	29	96	10	97	92	62	178	147	37	45	41	7.6	1.7	6.9	3.8	23
23.24		79.04	7.60	4.18	0.67	0.63	0.44	1.24	0.40	0.16	0.19	220	12	73	41	34	109	10	88	102	50	165	140	32	44	36	5.5	1.4	6.1	3.2	17
23.25		81.47	7.28	3.72	0.53	0.36	0.49	1.06	0.40	0.20	0.16	211	11	71	30	34	65	9	89	88	31	167	190	24	44	27	3.9	1.0	4.3	2.3	15
23.26		66.85	6.16	3.19	0.58	9.89	0.41	1.05	0.32	0.21	0.15	214	11	51	33	26	68	7	188	78	27	139	153	21	34	23	3.2	0.9	3.5	1.8	18
23.27		55.19	5.50	9.88	0.40	4.52	0.33	0.79	0.28	1.82	0.75	651	18	49	102	34	70	6	196	80	26	215	122	19	31	23	2.9	1.0	5.7	1.8	17

		SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	Ba	Co	Cr	Cu	Li	Ni	Sc	Sr	V	Y	Zn	Zr	La	Ce	Nd	Sm	Eu	Dy	Yb	Pb
23.28		52.05	5.11	10.87	0.36	4.32	0.34	0.73	0.25	1.93	1.91	1040	30	33	106	31	112	6	215	78	25	232	108	18	30	26	2.7	0.9	10.0	1.8	17
23.3		58.38	5.56	9.72	0.39	3.15	0.36	0.79	0.28	1.68	0.98	636	19	42	84	35	75	6	171	75	24	237	126	18	28	23	3.0	0.8	6.9	1.7	17
23.4		53.25	5.48	12.55	0.40	3.70	0.34	0.76	0.28	2.08	1.13	771	23	45	106	35	81	6	200	88	25	277	134	19	32	25	2.6	1.0	7.4	1.9	43
23.5		47.65	5.19	22.29	0.37	1.89	0.29	0.71	0.24	1.43	2.62	924	41	21	104	25	97	5	129	87	24	254	105	17	30	29	3.2	1.3	13.4	2.0	21
23.7	**2/3**	69.87	6.93	3.32	0.55	6.93	0.44	1.12	0.35	0.37	0.08	219	8	57	39	34	49	8	169	80	27	138	142	23	40	25	3.8	0.9	3.4	1.8	14
23.8	**1/3**	71.27	6.95	4.98	0.46	4.16	0.51	1.02	0.35	1.13	0.45	388	13	55	86	41	64	7	163	76	27	236	155	23	42	27	3.8	0.9	5.3	1.8	18
23.8	**2/3**	71.07	6.87	4.92	0.48	4.12	0.49	1.01	0.36	1.15	0.46	416	13	56	83	41	65	8	168	78	28	232	147	24	44	27	4.1	0.9	5.0	1.8	19
23.8	**3.3**	70.80	6.80	4.90	0.46	4.10	0.49	1.00	0.35	1.13	0.47	400	13	55	80	40	65	7	166	75	27	229	163	23	40	27	3.4	0.9	5.7	1.9	18
23.9	**1/3**	72.28	7.16	4.01	0.55	5.45	0.50	1.09	0.37	0.62	0.37	325	14	58	49	37	71	8	166	82	31	190	204	26	47	29	4.5	1.0	5.1	2.0	18
23.9	**2/3**	72.12	7.17	4.08	0.55	5.99	0.48	1.11	0.37	0.59	0.37	319	15	58	48	36	72	8	171	81	31	181	157	25	44	28	4.3	1.0	5.0	2.2	18
23.9	**3/3**	72.25	7.09	4.02	0.55	5.80	0.48	1.10	0.38	0.58	0.36	316	14	59	53	40	72	8	169	81	31	184	146	25	40	28	4.1	1.0	5.0	2.1	21
23.302	**HA/MS**	30.45	3.28	45.47	0.45	2.97	0.20	0.43	0.21	3.56	5.23	1609	52	1	92	16	146	5	208	136	38	320	90	24	41	45	6.9	2.6	24.0	3.7	24
23.303	**HA/MS**	31.94	3.32	42.52	0.54	4.29	0.21	0.52	0.23	5.56	4.31	2074	42	13	73	15	111	5	375	118	36	475	84	21	39	39	5.6	2.4	21.0	3.4	26
23.304	**HA/MS**	42.13	4.74	42.21	0.48	2.32	0.27	0.60	0.26	1.85	2.07	660	50	30	150	27	101	5	119	111	25	200	109	19	41	28	4.3	2.0	10.4	2.9	22
23.311	**HA/MS**	27.35	3.17	40.77	0.39	5.49	0.21	0.44	0.19	5.54	3.80	2215	68	8	105	15	178	5	407	110	32	487	85	17	37	32	5.0	2.1	17.4	3.0	29
23.349	**HA/MS**	30.10	3.36	44.42	0.44	3.25	0.21	0.42	0.23	3.77	6.23	1793	52	6	45	16	128	5	254	188	36	327	90	22	43	47	6.5	2.5	28.4	3.7	26
23.355	**HA/MS**	65.97	6.98	17.07	0.50	1.33	0.42	1.09	0.34	2.30	1.17	689	50	74	48	29	101	8	169	119	25	381	124	25	58	31	4.2	1.4	8.2	2.2	36
23.82	**SL2**	25.20	2.19	56.47	0.62	3.16	0.14	0.35	0.13	2.83	6.14	1162	15	3	40	9	28	3	144	126	28	167	71	13	28	38	5.2	2.8	27.1	3.5	25
23.59	**SL1**	61.69	5.45	23.23	0.62	4.71	0.46	2.19	0.37	0.86	1.32	1121	18	52	27	28	43	6	176	82	31	61	133	22	40	29	4.9	1.6	9.3	2.6	10
23.63	**SL1**	29.50	4.28	61.28	0.88	6.24	0.35	1.38	0.24	1.64	2.89	1294	8	25	15	32	2	5	187	134	38	67	91	22	39	36	8.5	3.2	16.4	4.2	30
23.93	**SL2**	27.80	3.19	48.72	0.68	7.35	0.33	0.92	0.20	3.22	8.27	3608	15	18	31	15	48	5	380	148	44	172	62	21	39	57	7.3	2.7	40.0	4.1	22
23.53	**SL**	35.09	2.27	48.30	0.89	6.87	0.17	1.24	0.14	2.53	4.98	2313	10	9	13	9	7	3	269	99	32	74	59	15	34	38	5.8	2.7	25.0	3.1	24
23.82	**SL1**	29.30	2.49	61.49	0.68	5.70	0.26	1.49	0.17	1.65	3.76	3260	19	0	32	11	10	3	200	102	29	90	80	14	29	32	7.5	3.1	19.8	3.5	28
23.73	**SL1**	23.98	1.91	53.21	0.89	10.21	0.24	0.94	0.13	3.44	5.19	2357	15	13	31	8	13	2	335	114	25	98	62	12	28	35	5.9	2.9	24.9	2.8	29
23.59	**SL2**	23.71	1.92	72.14	0.75	4.67	0.19	0.99	0.14	1.44	1.16	606	37	23	75	8	52	2	142	102	18	88	61	9	34	14	6.3	3.4	6.4	3.3	32
23.57	**SL**	29.11	3.23	49.53	0.73	7.30	0.33	0.97	0.20	3.01	8.43	3405	12	18	25	15	30	5	372	146	43	140	103	20	35	58	7.3	3.0	41.7	4.0	26

ICP-MS data for KAY soils, slag and hammerscale; composition in ppm.

		U	Th	Rb	Nb	Cs	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Ho	Er	Yb	Lu	Ag	As	Pb	Cd	Tl	Mo	Sb	Bi	Sn
23.1		3.65	4.68	52	6.02	3.19	22	21.8	36.3	4.8	20.0	3.70	0.88	3.49	2.67	0.59	1.73	1.49	0.22	0.3	41.3	16	3.6	0.7	11.7	1.4	0.3	4.9
23.10	**1/3**	3.31	5.26	53	5.99	3.28	25	23.5	38.9	5.3	22.6	4.41	0.97	3.99	3.28	0.67	2.02	1.83	0.26	0.3	8.0	17	4.0	0.8	2.2	1.2	0.3	1.8
23.10	**2/3**	3.33	4.94	54	5.98	3.32	25	23.5	38.4	5.2	22.7	4.32	1.00	4.09	3.12	0.70	2.05	1.79	0.28	0.3	8.1	18	4.0	0.8	2.0	1.2	0.3	2.0
23.10	**3/3**	3.39	5.09	54	6.08	3.38	26	23.2	39.2	5.3	22.5	4.35	1.02	4.14	3.31	0.71	2.11	1.88	0.28	0.3	8.5	18	4.4	0.8	2.2	1.3	0.3	2.3
23.11	**1/3**	3.42	5.18	54	6.04	3.35	27	24.5	40.3	5.6	23.7	4.71	1.07	4.35	3.46	0.74	2.15	1.92	0.29	0.3	9.7	20	5.3	0.9	2.6	1.3	0.3	1.9
23.11	**2/3**	3.41	5.27	54	6.03	3.40	28	24.7	41.2	5.7	23.9	4.75	1.09	4.38	3.47	0.75	2.13	1.95	0.30	0.3	11.1	20	5.6	0.8	2.7	1.5	0.3	1.8
23.11	**3/3**	3.41	5.04	53	6.05	3.32	26	23.9	39.9	5.4	23.6	4.45	1.06	4.29	3.36	0.75	2.14	1.91	0.28	0.3	9.5	18	4.7	0.8	2.6	1.4	0.3	1.8
23.12	**4/9**	4.07	4.74	59	6.51	3.96	33	24.1	36.9	5.2	23.3	4.63	1.13	4.41	3.85	0.84	2.37	2.11	0.30	0.4	52.4	19	6.1	1.0	6.5	1.8	0.5	1.8
23.12	**8/9**	4.47	4.73	61	5.81	4.07	34	24.1	37.0	5.4	23.8	4.61	1.16	4.45	3.78	0.84	2.41	2.11	0.33	0.3	74.8	17	5.9	0.9	7.6	1.9	0.3	2.1
23.13		2.87	5.42	50	7.16	2.87	20	21.5	44.3	4.8	20.9	3.89	0.87	3.56	2.81	0.61	1.76	1.61	0.24	0.2	9.1	18	2.7	0.7	2.7	1.2	0.3	1.6
23.14		2.79	5.24	45	7.90	2.59	15	20.8	43.6	4.5	18.5	3.35	0.75	2.86	2.24	0.47	1.40	1.29	0.20	0.2	9.9	17	1.4	0.6	2.6	1.2	0.3	1.6
23.15		4.22	5.53	57	7.98	3.92	28	26.6	43.7	5.9	25.3	4.91	1.09	4.52	3.55	0.77	2.25	1.98	0.30	0.3	5.5	18	3.8	0.9	2.0	2.1	0.3	1.9
23.16		4.06	5.87	55	7.85	3.86	30	27.6	45.9	6.3	26.9	5.30	1.20	4.96	3.84	0.85	2.41	2.09	0.32	0.3	6.0	19	3.5	0.9	2.4	2.4	0.3	1.8
23.17		3.55	5.23	55	7.88	3.34	24	25.0	43.0	5.3	22.7	4.06	0.99	3.86	3.10	0.67	1.98	1.80	0.26	0.3	20.3	19	2.5	0.8	3.1	1.2	0.3	1.8
23.18		3.84	5.57	53	8.96	3.90	38	29.3	47.6	6.6	29.3	5.75	1.41	5.77	4.80	1.04	2.98	2.64	0.40	0.4	14.4	26	3.2	1.0	3.9	2.4	0.4	1.9
23.19	**1/3**	3.55	5.20	52	8.49	3.45	27	25.8	43.1	5.6	24.2	4.49	1.07	4.22	3.46	0.72	2.13	1.97	0.30	0.4	3.3	20	3.5	0.9	1.4	1.1	0.5	2.0
23.19	**3/3**	3.57	5.16	51	7.79	3.27	26	25.7	43.3	5.6	23.7	4.55	1.05	4.25	3.44	0.72	2.12	1.81	0.28	0.3	3.1	19	4.0	0.8	1.1	1.0	0.3	1.9
23.2		3.76	4.46	52	6.71	3.13	24	22.2	35.6	4.8	20.1	3.81	0.92	3.57	2.89	0.62	1.88	1.65	0.25	0.3	48.5	17	3.8	0.7	14.8	1.6	0.3	4.3
23.20		4.86	6.64	63	8.45	4.89	39	31.9	49.7	7.2	31.2	6.20	1.45	6.04	4.84	1.05	3.11	2.71	0.42	0.3	14.4	23	4.9	1.1	4.6	3.0	0.4	2.1
23.21		4.00	5.99	51	8.64	4.10	40	31.1	50.8	7.2	30.8	6.33	1.53	6.19	5.46	1.14	3.33	2.86	0.41	0.3	11.6	27	2.4	0.9	4.1	2.3	0.4	2.0
23.22		3.85	5.39	54	9.33	3.91	62	38.1	47.7	9.0	40.0	8.08	1.94	8.08	6.82	1.51	4.41	3.87	0.58	0.3	10.8	27	3.9	0.9	3.0	2.2	0.4	1.9
23.24		3.57	5.69	56	8.20	4.17	50	33.3	46.1	7.8	34.0	6.96	1.65	6.86	5.68	1.24	3.67	3.17	0.48	0.4	12.4	23	4.4	1.1	3.6	2.1	0.3	2.0
23.25		3.46	5.85	57	8.00	3.68	31	25.2	44.3	5.7	24.2	4.78	1.16	4.66	4.01	0.88	2.65	2.23	0.34	0.3	9.9	22	2.1	0.9	2.8	1.6	0.3	1.9
23.26		3.42	4.67	46	7.69	3.44	28	23.5	38.4	5.4	23.1	4.56	1.05	4.36	3.55	0.76	2.15	1.93	0.30	0.3	7.4	20	3.0	0.9	3.6	2.3	0.4	1.7
23.27		3.33	4.21	45	6.00	3.15	27	21.7	35.0	4.8	20.3	3.80	1.00	3.73	3.08	0.67	1.98	1.78	0.27	0.5	33.6	17	8.4	0.8	5.8	2.4	0.3	2.2
23.28		3.23	3.79	43	5.66	2.87	26	20.1	32.3	4.4	19.4	3.73	1.10	3.52	2.91	0.62	1.85	1.63	0.26	0.3	39.0	15	15.2	0.8	13.1	2.6	0.2	1.8

		U	**Th**	**Rb**	**Nb**	**Cs**	**Y**	**La**	**Ce**	**Pr**	**Nd**	**Sm**	**Eu**	**Gd**	**Dy**	**Ho**	**Er**	**Yb**	**Lu**	**Ag**	**As**	**Pb**	**Cd**	**Tl**	**Mo**	**Sb**	**Bi**	**Sn**
23.3		3.13	4.02	46	5.62	3.05	24	20.0	32.8	4.5	18.8	3.79	0.95	3.40	2.79	0.62	1.80	1.62	0.25	0.3	29.1	17	9.1	0.8	6.9	2.0	0.3	2.2
23.4		3.45	4.00	44	6.06	3.00	26	20.8	33.9	4.6	19.3	3.77	1.02	3.53	2.88	0.63	1.87	1.69	0.27	0.4	45.4	45	9.5	0.9	8.8	3.0	0.5	12.2
23.5		5.22	3.81	41	5.14	2.72	24	19.5	30.5	4.3	18.4	3.47	0.99	3.38	2.70	0.62	1.74	1.52	0.24	0.3	140.6	17	4.7	0.7	33.7	3.0	0.3	5.0
23.7	**2/3**	3.62	5.33	54	7.65	3.69	27	25.8	41.6	5.8	24.9	4.72	1.12	4.50	3.53	0.75	2.18	1.98	0.30	0.4	10.1	18	2.2	0.8	2.3	1.6	0.3	1.8
23.8	**1/3**	3.49	5.07	54	6.79	3.48	26	23.9	39.8	5.3	23.1	4.51	1.06	4.20	3.33	0.73	2.13	1.88	0.28	0.4	16.0	21	5.7	0.9	3.1	1.4	0.3	2.1
23.8	**2/3**	5.70	8.95	93	12.63	6.11	47	43.5	72.0	9.7	40.8	7.65	1.75	7.33	5.73	1.23	3.51	3.21	0.48	0.6	28.3	35	10.2	1.5	5.5	2.5	0.7	3.8
23.8	**3.3**	3.64	5.45	55	7.24	3.75	28	26.1	43.0	5.8	24.9	4.78	1.12	4.52	3.66	0.78	2.26	2.06	0.31	0.4	17.3	22	6.5	0.9	3.5	1.6	0.4	2.7
23.9	**1/3**	3.94	6.00	59	7.75	4.10	33	30.1	49.3	6.8	30.1	5.57	1.29	5.39	4.27	0.92	2.75	2.41	0.35	0.4	13.8	23	5.7	1.0	3.5	1.9	0.4	2.0
23.9	**2/3**	4.29	6.50	63	8.34	4.48	37	32.7	52.3	7.3	32.0	6.11	1.41	5.85	4.63	1.03	2.97	2.57	0.39	0.5	15.0	25	6.2	1.1	4.0	2.0	0.4	2.2
23.9	**3/3**	5.37	8.04	86	11.93	5.85	49	42.6	67.5	9.5	40.6	8.13	1.82	7.44	5.97	1.29	3.72	3.29	0.50	0.7	20.1	32	7.9	1.4	5.2	3.0	0.5	3.0
23.302	**HA/MS**	6.07	3.83	26	5.52	1.48	51	34.6	51.4	7.6	34.9	6.88	2.08	6.98	5.65	1.22	3.49	3.00	0.45	0.4	126.9	17	35.9	1.3	60.6	3.2	0.3	5.5
23.303	**HA/MS**	5.21	2.71	18	4.36	0.94	35	22.8	34.2	4.9	21.9	4.51	1.52	4.60	3.80	0.83	2.32	2.01	0.30	0.3	63.3	14	27.9	0.6	33.3	1.7	0.2	1.8
23.304	**HA/MS**	3.74	3.84	37	5.04	2.34	25	21.3	35.7	4.7	20.0	4.01	1.02	3.82	3.02	0.67	1.96	1.75	0.25	0.4	116.3	14	8.2	0.7	48.7	2.0	0.2	3.0
23.311	**HA/MS**	3.75	2.37	17	3.71	1.12	30	18.6	27.7	4.0	17.8	3.49	1.31	3.76	3.13	0.68	2.00	1.81	0.27	0.3	121.8	14	34.0	0.8	47.4	2.7	0.3	9.8
23.349	**HA/MS**	4.61	3.00	17	4.40	0.93	33	23.9	37.4	5.2	23.6	4.55	1.45	4.76	3.73	0.83	2.31	1.97	0.28	0.3	81.5	14	25.8	0.7	31.5	2.3	0.2	1.2
23.355	**HA/MS**	3.28	4.79	37	6.09	1.88	23	24.9	51.7	5.6	23.6	4.57	1.13	4.41	3.32	0.67	1.91	1.64	0.23	0.3	21.1	31	7.3	0.6	10.9	2.3	0.4	1.7
23.82	**SL2**	3.19	1.68	13	2.07	0.67	24	14.9	21.1	3.2	14.5	2.99	0.90	3.02	2.51	0.57	1.65	1.57	0.25	0.2	13.0	4	5.2	0.2	9.4	0.9	0.1	1.0
23.59	**SL1**	3.98	4.16	39	6.01	2.10	29	22.9	36.5	4.9	21.5	4.23	1.19	4.21	3.36	0.78	2.22	1.97	0.31	0.2	11.4	6	0.8	0.3	38.1	0.8	0.1	0.9
23.63	**SL1**	9.11	3.16	24	4.54	0.68	36	23.2	37.1	5.2	22.7	4.54	1.30	4.59	3.92	0.89	2.58	2.25	0.35	0.2	2.8	2	0.5	0.1	2.8	0.1	0.0	0.6
23.93	**SL2**	12.38	2.73	15	4.22	0.75	42	24.0	36.0	5.2	23.6	4.89	1.98	5.18	4.44	0.99	2.86	2.53	0.39	0.2	31.3	3	8.4	0.6	11.3	0.6	0.1	0.8
23.53	**SL**	4.09	2.04	27	2.60	0.61	30	17.2	26.1	3.8	16.7	3.50	1.41	3.66	3.13	0.69	2.02	1.77	0.26	0.1	5.4	1	1.5	0.1	4.2	0.4	0.0	0.5
23.82	**SL1**	4.39	2.20	19	3.45	0.60	28	17.3	25.2	3.7	16.2	3.34	1.52	3.44	2.95	0.66	1.90	1.71	0.26	0.2	5.5	2	1.6	0.1	32.0	0.3	0.2	1.5
23.73	**SL1**	7.24	1.56	26	2.90	0.50	24	15.4	21.6	3.2	14.0	2.86	1.23	3.00	2.34	0.56	1.52	1.29	0.20	0.2	29.3	2	3.6	0.1	20.2	0.6	0.1	2.1
23.59	**SL2**	3.03	1.52	17	2.92	0.45	17	10.9	16.5	2.3	10.5	2.14	0.62	2.03	1.79	0.40	1.20	1.05	0.16	0.2	115.7	1	1.7	0.1	63.3	1.4	0.0	1.1
23.57	**SL**	12.78	2.72	17	4.63	0.83	46	25.3	37.9	5.5	24.3	5.08	2.06	5.34	4.52	1.01	3.02	2.55	0.38	0.2	12.7	3	5.9	0.4	8.1	0.4	0.1	0.8

5.4 Statistical Treatment of the data for soils from KAY

Discriminant analysis, is offered as the best tool for an independent assessment of the differences between the compositions of three groups i.e. soils, hammerscale and slag. Figure 6 shows the scores for discriminant function (DF1 vs. DF2) and how well the three groups can be discriminated from each other. To calculate the DF functions all data in Table 3 have been used. There is clearly no overlap – or outliers - between the three groups.

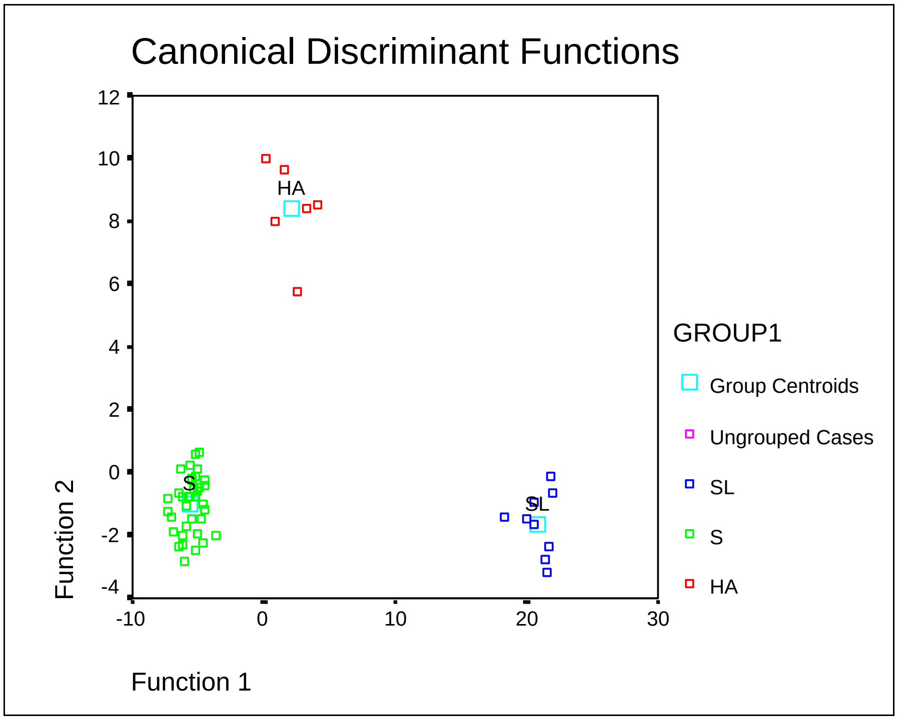


Figure 6: Plot of DF1 vs. DF2 for the samples belonging to three groups: slag (SL), soils (S) and hammerscale (HA). The three groups are quite distinct with no outliers.

Although good separation between slag and the other two groups would be expected, similar good separation between hammerscale and soils cannot be taken for granted since ferrugenous soils can often be mistaken for hammerscale. The good separation between hammerscale and soils seen here can be taken as an indication that the rest of the samples labelled as such are indeed hammerscale.

The next stage in maximising the information which can be obtained from the available data is to incorporate other measured variables such as magnetic susceptibility and LOI within the ICP-OES set of soil analyses. The point of the exercise is to establish, if possible, whether some soils derive from metallurgical features while others do not. Principle component analysis rather than discriminant analysis is the package to use.

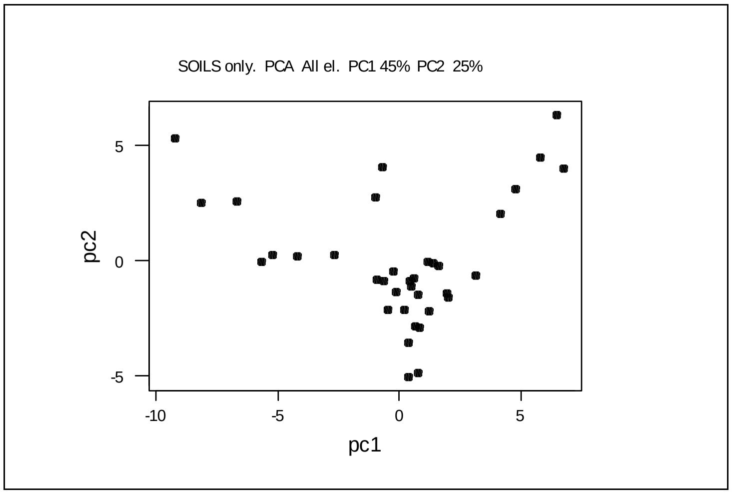


Figure 6a: PC analysis for soils, all elements

Figure 6a shows principle component analysis, a statistical package better suited for differentiating between members of the same group (in this case soils). PC analysis shows that although the soils may form a distinct group, with respect to hammerscale and slag, there is a considerable spread within the group proper.

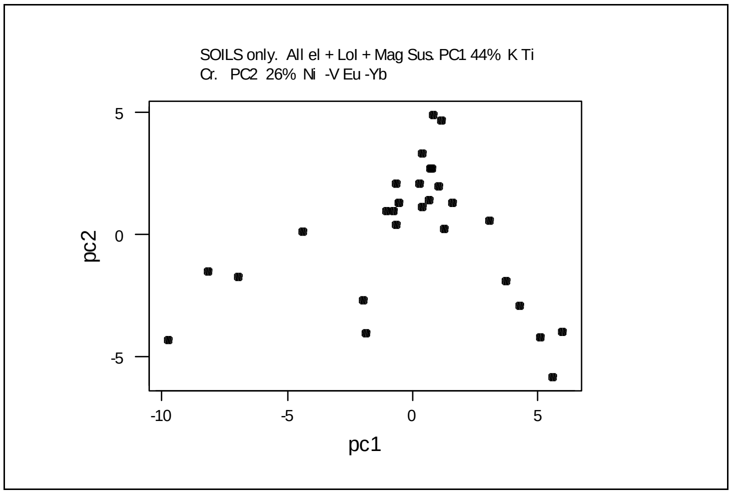


Figure 6b. PC analysis for all elements and mag susc and LOI

In order to "force" this differentiation further, other parameters are plotted as well namely mag. susc. and LOI. However, as Figure 6b shows even with the two new parameters no better separation is achieved. This may be due to an insufficiently large group of samples from different features as opposed to many samples from the same feature like in the case of C364 or that simply mag. susc. on its own may be adequate for processing large number of soils and providing a first stage interpretation of the feature.

6.0 SEM-EDAX examination and analysis

6.1 Sample Preparation

Fragments of slag were cut across with a diamond-bearing cutting wheel and the section was mounted in metallographic resin, ground with a series of silicon carbide papers and polished with 6 and 3-micron diamond pastes. The polished block was subsequently carbon-coated in preparation for SEM-EDAX analysis (see *Table 9). The* polished block was examined with the scanning electron microscope (a Leo stereoscan-S360) attached to an ISIS analyser with ZAF correction package. All elements shown in the *Table 9* were sought, the composition given in weight per cent. Internal calibration was carried out using a Co standard. Operating voltage was 20Kev and working distance was 25mm. Typical limits of detection for SEM-EDAX are of 0.1%wt-0.5%wt. Elements with values below the limit of detection are denoted as nd. The sample was examined with the backscatter detector. A methodology for examination and analysis of metallurgical waste from archaeological sites has been outlined in numerous publications and has been summarised in the relevant English Heritage (2001) publication. Operating conditions for the SEM-EDAX and levels of sensitivity for each element are given above.

6.2 Methodology

The methodology for SEM-EDAX analysis followed by SASAA is outlined here. Analyses are undertaken first on the entire surface of the polished block, and subsequently on each of the different mineralogical phases. Both sets of analyses are needed. The rationale behind such practice is that direct comparisons between analyses can only be made only between phases of similar mineralogical composition. The first type (taken over a mean of three) represents area or bulk chemical analysis and is considered to be representative of the composition of the sample as a whole. As such, it identifies the slag as metallurgical of the ferrous or non-ferrous variety. The second type is aimed at establishing the composition of each of the mineralogical phases within and so at identifying the process that generated it. In brief, spot analyses are aimed at establishing whether the slags are of the smithing or smelting variety and provide information on the environment, temperature and conditions within the furnace in question.

6.3 Analysis

23.53 SL*: Figure 7a*

Round nodules of iron oxide as well as fully grown ones within the underlying cavity consisting of iron oxide and calcium carbonate; the latter must have formed as a result of re-crystallisation of excess calcium as suggested by the zoning effect.

23.57 SL: *Figure 7b*

This is a fayalitic slag, the interstitial glass shows a number of micro-phases among which angular grains of calcium phosphate as well as fayalite rich in calcium; also potassium rich glass. All phases are the result of slow cooling.

23.59 SL2: *Figure 7c*

Dendrites of wustite growing at angles to each other amidst fayalite grains. There is a minimal amount of interstitial glass which appears weathered at places. Large overgrown needles of fayalite densely distributed and allowing little space for interstitial glass to grow. Fine dendrites of wustite and fayalite precipitate out of the glass. The slow rate of cooling is evidenced by the coring seen in the grains of fayalite.

23.82SL1: *Figure 7d*:

Growth of fine dendrites of wustite within glass; calcium phosphate phases (dark grey) calcium rich fayalite (light grey) and wustite (white); also glass (black).

Also large (about 20microns across), irregularly shaped grains of calcium phosphate.

23.93SL1

This is a fayalitic slag rich in calcium with small amounts of manganese. The interstitial glass consists of a number of crystalline phases consisting of a) dendrites of wustite, b) calcium rich fayalite, c) a K-rich calcium iron silicate. The interstitial glass is a potassium alumino-silicate.

23.93SL2: ***Figure 7e***

Same as 23.93SL1. This is also a fayalitic slag rich in calcium with small amounts of manganese. The interstitial glass consists of a number of crystalline phases a) dendrites of wustite, b) calcium rich fayalite, c) a K-rich calcium iron silicate. The interstitial glass is a potassium alumino-silicate. The wealth of phases seen in Figure 7e suggests a slow cooling rate consistent with the slag forming within the bowl furnace and allowed to cool prior to removal.

23.96 SL*: Figure 7g*

This is primarily an iron oxide rich slag with small amounts of manganese and calcium oxide. **Figure 7g** shows secondary emission image of a cavity filled with re-precipitated calcite coating an iron oxide core. The cavity appears dark because of the coating of calcite on the iron oxide dendrites. (bar=200microns; x=192). Fragments of charcoal are shown trapped within the slag. The wood might be oak or hazel. The presence of manganese, calcium and phosphorus suggest that it is a smelting slag.

General Statement regarding slags

In their overall composition, the slags are either fayalitic (iron silicates) or wustitic (iron oxides). However a number of other phases are present albeit to a smaller extent. The characteristic feature of the KAY slags is their high calcium content. Calcium enrichment is seen in three “guises”:

a) Calcium enrichment within the fayalite varies from 5-20%; revealing two types of fayalite, a high calcium and a low calcium one. These two phases appear on backscatter mode as grey and white respectively (see Figure for 23.53SL)
b) Calcium re-precipitation seen clearly in Figure for 23.53SL. Calcium oxide eventually will be converted to calcite which coats the surface of iron oxides. The latter might be rich in manganese.

c) A complex glassy phase consisting of Ca-P-Si-Fe, calcium phosphate phase which might be rich or poor in iron as seen in Figures for 23.82SL1. This is clearly a glass since the ratio of calcium to phosphorus varies in different samples and within the same sample. Bone or hydroxyapatite has a Ca/P ratio of 4/1 and certainly does not accommodate silica and iron oxide at the levels present here. What is the source of this phase which appears to form a characteristic of the KAY slags. It may be that phosphorus is of organic origin (peat-related) rather than inorganic associated with bone.

Overall the range of complex micro-crystallinity suggests that the slags are mostly of the smelting variety and that they have cooled slowly within the bowl furnace. The origin of the phosphorus rich phase may be crushed up animal bone added to the furnace. Calcium would render the slags viscous but it is possible that the intention of the smith might have been to add the phosphorus as a flux (phosphorus–rich glass). This is a question which requires a separate line of investigation well beyond the confines of the present report. Alternatively the phosphorus might be organic in origin and might be a mineral within the peat. Indeed when examining the contents of vitrified fuel ash from Orkney (Photos-Jones 2003) an aluminium, iron phosphorus mineral was observed trapped in remains of a fragment of peat/turf.

Table 9: SEM-EDAX semi-quantitative analyses of metallurgical waste : composition in weight percent; nd = not detected

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO	BaO
23.96 SL area analysis 1	nd	0.59	1.94	16.26	1.36	nd	nd	3.27	nd	2.12	73.75	nd
23.96SL fayalite spot analysis	nd	0.82	nd	30.26	nd	nd	nd	5.23	nd	5.76	60.41	nd
23.96SL wustite spot analysis	nd	nd	0.33	0.37	nd	nd	nd	nd	0.28	1.99	96.70	nd
23.96SL fuel analysis un-normalised	nd	nd	nd	3.97	1.01	Nd	Nd	0.81	nd	0.72	58.09	Nd
23.93SL1 area analysis 1	0.36	0.55	2.22	25.66	1.66	0.33	1.90	14.94	nd	9.02	42.75	0.69
23. 93SL1 (Fig SL123) wustite	nd	nd	nd	0.42	nd	nd	nd	0.40	0.85	2.62	95.16	nd
23.93SL1 (Fig SL123) Ca-rich fayalite	0.31	0.23	nd	26.83	1.22	nd	0.25	22.46	nd	6.49	41.91	nd
23.93SL1 (Fig SL123) K-rich fayalite	1.98	nd	3.98	39.41	1.76	3.04	11.70	6.76	0.94	1.21	21.91	7.19
23.93SL1 (Fig SL123) glass	0.23	nd	27.70	41.01	nd	nd	27.70	nd	nd	nd	2.63	nd
23.53SL area analysis 1	nd	0.61	3.08	45.16	2.04	nd	1.22	8.49	nd	4.88	33.55	nd
23.53SL (Fig.SL112) Ca-Fe ppt	nd	nd	nd	nd	1.00	0.27	nd	70.22	nd	nd	23.88	nd
23.53SL(Fig.SL112) Ca-Fe other ppt	0.34	nd	nd	0.33	1.05	nd	nd	57.57	nd	15.13	25.63	nd
23.53SL (Fig.SL112) fayalite	0.22	1.31	nd	28.59	0.65	nd	nd	3.27	nd	8.47	57.58	nd
23.53SL (Fig.SL112) glass	0.44	nd	5.83	77.03	2.65	0.42	2.67	6.69	0.51	0.34	3.06	nd
23.53SL **(Fig.SL115) light phase**	0.60	0.25	2.03	26.04	8.12	nd	1.24	16.31	nd	3.05	41.94	nd
23.53SL **(Fig.SL115) dark needles**	nd	0.43	0.82	40.43	1.40	nd	0.75	30.90	nd	3.98	20.83	nd

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO	BaO
23.59 SL2 area analysis 1	0.46	0.56	2.31	20.93	1.59	nd	1.30	8.09	nd	1.16	63.30	nd
23.59 SL2 area analysis 2	0.39	0.46	2.16	21.19	1.48	nd	1.13	7.74	nd	1.02	64.26	nd
23.59SL2 fayalite	nd	0.80	nd	28.80	nd	nd	nd	5.23	nd	1.56	63.14	nd
23.59SL2 wustite	nd	nd	0.39	0.69	nd	nd	nd	nd	nd	0.32	97.71	nd
23.59SL2 calcium phosphate	0.67	nd	0.14	3.28	29.55	0.36	0.74	53.66	nd	2.34	9.25	nd
23.59SL2 glass consisting of two phases	0.83	nd	5.21	28.46	5.07	0.50	4.61	24.62	nd	0.56	29.86	nd
23.82SL1 fayalite	nd	nd	nd	28.62	0.35	nd	nd	8.97	nd	10.48	51.32	nd
23.82SL1 calcium phosphate	0.62	0.19	1.07	9.70	22.13	0.22	1.25	27.86	nd	4.27	22.30	nd
23.82SL1 calcium phosphate	0.62	0.19	1.07	9.70	22.13	0.22	1.25	27.86	nd	4.27	22.30	nd
23.59SL2 calcium phosphate	0.67	nd	0.14	3.28	29.55	0.36	0.74	53.66	nd	2.34	9.25	nd

7.0 Discussion/Conclusions

KAY has a tight chronological span, i.e. 7^{th}-9^{th} or 10^{th} AD (see C-14 dates in main report). The MW output is commensurate with the duration of the life of the site. The number of furnaces/smithing hearths suggest that iron-making was not necessarily a frequent activity and that the bulk of the KAY smith's work would have been forging and mending of tools. Yet the proximity to the domestic structures suggests an "intimacy" with iron making, in other words the smith resided in KAY. There is a total of ten features which are clearly metallurgical: these are summarised on the table below and have been classified as furnaces (BF) or hearths (BH) on the basis of their dimensions and shape, the enclosed material evidence (charcoal and slag) and magnetic susceptibility readings associated with their fills. Table 1 below summarises these features.

Table 1. Main metallurgical features

Type of features	Context No	Dimensions/description
pits	420BF	Oval BF; Sub-circular in plan, sides steeply sloped, base mostly flat; 0.44m wide x 0.13m deep
	424BF?	Sub-oval in plan, sides slope gradually, base nearly flat, small ledge at eastern end ; 0.75m x 0.50m x 0.12m deep
	426BH	Stepped Oval pit; 1.17m x 0.56m x 0.39m deep; slopped base/vertical sides;
	437BF	Oval pit; 0.42m x 0.36m x 0.08m; flat base; gradual break of slope
	540BF	Circular in plan, sides steeply sloped, base flat; 0.40m wide x 0.08m deep
	610BH	Circular pit; 0.84m x 0.74m x 0.12m; gradual sloping sides; flat base.
	861BH	Keyhole or figure of eight shape on plan, base undulating and concave, getting deeper towards SE end. Sharp break of slope at top of cut, gradual break of slope at NE end, sharp at SW end; 2.49m x 0.31-0.97m wide x 0.29m deep
	482BH	Sub-rectangular pit, N-S orientation, sides slope gradually, base is irregular. 0.40m x 1.50m x 0.15m deep
	561BF	Linear pit. Sides concave and steeply sloped, base is concave. 0.40m x 0.19m deep
	608BH	Pit, sub-oval in plan. East side vertical others gently sloped, base irregular. 0.34m x 0.60m x 0.10m deep
	616	Curvilinear gully/windbreak. Sides concave base flat. 0.53m x 3.80m x 0.13m deep

Bloomery Bowl Furnace typology

The bowl furnaces (BF) include C420, C437, C540 and C561. They consist of an oval or circular shaped feature on the average c. 40cm, rather shallow, flat bottomed, with steep sloping sides, and two or more fills which are full of charcoal and slag. The shallow furnace depth points to a dismantled furnace. It should be noted that bowl furnace dimensions nearing a ratio of Depth/Width=1 would have been required, to allow for space for the bloom to form. The stepped feature C426 corresponds more to the expected original dimensions of a BF with an added platform for the bellows/tuyere to rest on. But it could also be a hearth. The overall small size of the tuyere is commensurate with a bowl furnace of the diameter seen here. What is less certain is the type of bellows that would have been used (see below).

Bloomery Hearth Typology

The bloomery hearths (BH) include C426 (perhaps combined with furnace), C610, C861, C482 and C608. They have gradually sloping sides and a rectangular shape, with on average c.30cm depth. The hearth floors would not have been dismantled and so the depths recovered must reflect their original depth. Both bloomery furnaces and hearths mentioned so far are associated with metallurgical Area A. Metallurgical Area B comprises only of C861.

C861 is a hearth on account of its size and the distribution of contexts with high magnetic susceptibility readings**.** Together with C610, they sit further away from the main areas of working and as such may date earlier or later from the main phase of activities.

Other features

C364 is not a cistern as originally suggested; it is rather a dumping pit. It is difficult to assign a function to features C27, C24, C23 and C114 in Area A. There is no clear suggestion that Area A was involved in metal working at all.

Tuyere typology

There was only one tuyere, complete, found at KAY, see figure 1c (02E1002:395:1). The tuyere 's hole is 3cm wide, narrowing to 1.7cm; the overall piece is 8.5 cm high and of 6cm max width. The tuyere hole is at a c. 30 degrees angle to the base. The hole points upwards or downwards depending on the positioning of the base. The slagging of the exterior (the part that would have been in direct contact with the heat/interior of the furnace) concentrates around the hole. Although no samples have been taken from the tuyere, it is suggested that "slagging" should be interpreted as melting of the ceramic fabric rather than as the product of reaction with the interior of the furnace. There are faint striations across the interior of the hole generated either by the insertion of a hollow reed through which the air was blown or formed in the course of making of the tuyere. The tuyere must have been free standing and part of the smith's "tool kit". Its small size implies portability as does the source of the air supply, the bellows. It may have been simply the smith’s lungs! Figures 1c and 8 illustrate various aspects of the tuyere.

Materials

A total of 86 kg of MW was retrieved from the site, measured and weighed. Among the slag examined the majority were of the smelting variety on account of the multiplicity of phases within, to include calcium-rich fayalite and calcium-phosphates. Smithing slags comprised, as expected, of iron and silica only (wustite and/or fayalite). Bog ore must have been the ore used, on account of the manganese and (some) phosphorus present; however, the calcium present in the slag needs to be attributed either to the ore or to the addition of bone (?). There has been no single satisfactory explanation for the origin of the calcium in the KAY slag. Furthermore the possible location of the original bog ore source in relation to the site still remains to be ascertained. The fuel was most probably hazel (for kindling wood) and oak for smelting charcoal.

Judging from the amount of the slag, the metalworking activities on site could not have been of a long duration. The output is commensurate with the duration of the life of the site which is dated to 9th-10th AD. The number of furnaces / smithing hearths reflect that low intensity activity since the bulk of the KAY smith's daily work would have been forging and mending of tools. Only on occasions would he have made the raw material from which the baulk of the MW derives. In many respects, KAY does not present a parallel story with the activities at Johnstown I since the waste there exceeded two metric tons and spanned a much longer chronological period, from the 6-7th- 14th century AD. Neither does it fit tightly with the other sites along the KEK-M4 motorway scheme (see compiled Photos-Jones 2003 bibliography under ACS Ltd) which, more often than not, present an image of the lone smith returning to the "industrial grounds" for making iron when the need takes him. To our view KAY appears to be a farmstead sufficient in its own needs but also open to the outside world. Apart from iron making and working it may be that some areas may have been targeted for specific type of gender-related activities. If this is correct it may be that women occupied themselves with some crafts while men, or at least some of them, got on with making their iron. All these activities must have been going on top of the daily agricultural routine of farmers living off and working this agriculturally rich land in Kildare. By calling the metal working activities at KAY industrial it is perhaps a case of pushing the evidence a bit too far. To the view of the present writer, iron, at least bloomery iron making and working should be seen not as an industrial process but as part of the cycle of a farmers yearly calendar of activities.

Regarding the quality of iron found at KAY*:*

Of the two objects analysed only one had sufficient metal remaining to derive any conclusions from. Analysis of six slag inclusions in each artefact shed light in their provenance. The calcium-rich slag inclusions within the chisel were certainly reflecting the calcium rich fayalite and glass observed in the smelting slags. The presence of such high amounts of calcium in the slag (c.8-10%Ca0 by SEM-EDAX area analysis on the polished surface) were rather unusual at least in relationship to the other KEK-M4 sites. The origin of this calcium needs to be traced either in the accidental?) addition of bone or in the sideritic origin of the ore? The mineral formed is actually calcium-iron-phosphate and in many respects it is the one that fingerprints the KAY slags and its artefacts.

The knife displayed none of these fingerprinting phases. There may be two reasons for that: either the inclusions analysed were derived from the forging stage or the artefact was an import. While it was not possible to draw any conclusions regarding the quality of the iron in the knife, the chisel was much more revelatory. First it was evenly carburised throughout showing tight control from the point of view of the smith in both choosing the appropriate bloom (low in slag inclusions) and second in achieving uniform. Chisels are often seen to be made of phosphoric iron since they work harden during use. It is highly likely that the KAY smith would exercise similar type of control on other quality objects be it tools or weaponry.

It is not possible to speculate on the quantity of artefacts produced on site, and to refer to tool-making as "high quality specialist work" would appear to be unnecessarily patronising the KAY smith. Putting it pedantically, he knew what he was doing, and had he had a need for a chisel he would have made one and had he had a need for a good knife/dagger, he would have made one, as well.

It is also not possible to ascertain the extent to which the KAY smith was involved in the manufacturing of other metal artefacts. Perhaps the more appropriate question to ask would be whether the KAY smith had any "urgent" need for copper/bronze artefacts, let alone precious metals; whatever would have been required, he would have been in a position to get via trade or exchange from market towns or itinerant tinker/merchants.

Regarding comparison with other sites, in many respects, KAY does not present a parallel story with the activities at Johnstown I, only c.7km to the west, since the waste there exceeded two metric tons and spanned a much longer chronological period, from the 6-7th - 14th century AD. Neither does it fit tightly with the other sites along the KEK-M4 motorway scheme (see compiled Photos-Jones 2003 bibliography under ACS Ltd) which, more often than not, present an image of the smith, away from a home base, returning to well known “industrial grounds” for making iron when the need took him. There should have been no need for trade in raw materials only perhaps trade in finished objects; the reason is that both ore and fuel must have been ubiquitous and democratically available to all.

A site like KAY may have been in the 8th century’s jurist’s mind when he composed the tract ***Blai ord indeoin.*** “…a lively workplace, manned by a number of workers engaged on various tasks while their customers wait around for their work to be completed”. Scott (1983, 62) paints a vivid image of the jurist, who although “couching his writings in the stilted jargon” of the jurists of his time had or developed “a feeling for good workshop practice and a sympathy with those who plied the blacksmith’s trade”. KAY may have attracted churchmen like the author of the above and laymen alike who might have come for business or stopped over on their travels. The pins, blue beads and elaborately decorated combs (Walsh 2003) certainly point to a “lively place” sufficient in itself but also open to the outside world.

8. References

ACS Ltd 2003

Photos-Jones E, 2003, Analysis of Metallurgical Waste from the M4 Kinnegad-Enfield-Kilcock Motorway Scheme, the Johnstown I site, SASAA 88, October 2003.

Photos-Jones E, 2003, Analysis of Metallurgical Waste from Ballyonan, SASAA 96, October 2003.

Photos-Jones E, 2003, Analysis of Metallurgical Waste from Griffinstown III SASAA 98, October 2003.

Photos-Jones E, 2003, Analysis of Metallurgical Waste from Hardwood III, SASAA 99, October 2003.

Photos-Jones E, 2003, Analysis of Metallurgical Waste from Johnstown III SASAA 99, October 2003.

Photos-Jones E, 2003, Analysis of Metallurgical Waste from Kinnegad II, SASAA 93, October 2003.

Photos-Jones E, 2003, Analysis of Metallurgical Waste from Newcastle II, SASAA 92, October 2003.

Photos-Jones E, 2003, Analysis of Metallurgical Waste from Rossan III, Rossan IV, Rossan V and Rossan VI, SASAA 90, 94, October 2003.

Photos-Jones E, 2003, "If it works, do not fix it": Early (and later) Iron Working in Ireland along the KEK-M4 Motorway Scheme, DRAFT 09/03

Addyman P.V, 1965, 'Coney Island, Lough Neagth: prehistoric settlement, Anglo-Norman castle and Elizabethan native fortress' *Ulster Journal of Archaeology* 28, 78-101

Clarke L, 2003, The K-E-K M4 Motorway, Johnstown I, ACS Ltd Report

Collins AEP, 1955, Excavation at Lough Faughan crannog, Co. Down 1951-52, *Ulster Journal of Archaeology* 18, 45-81.

Edwards N, 1996, *The Archaeology of Early Medieval Ireland*, B.T. Batsford Ltd London.

English Heritage, 2001, *Centre for Archaeology Guidelines: Archaeometallurgy*, Sterling Press Ltd.

Fanning T, 1981, Excavation of an Early Christian cemetery and settlement at Reask, Co. Kerry, *Proceedings of the Royal Irish Academy* 81C, 3-172.

Hall AJ and Photos-Jones E, 1998, The bloomery mounds of the Scottish Highlands: Part II – a review of iron mineralisation in relation to the Scottish Highlands Bloomeries, *J. Historical Metallurgy Society*, 32 (2), 54-66.

Harbison P, 1980, *Pre-Christian Ireland, From the First Settlers to the Early Celts*, Thames and Hudson.

Harper AET, 1972, The excavation of a Rath in Mullaghbane Townland, Co. Tyrone, *Ulster Journal of Archaeology* 35, 37-45.

Hencken HO'N, 1950, Lagore crannog: an Irish royal residence of the seventh to tenth centuries AD, *Proceedings of the Royal Irish Academy* 53C, 1-247.

Mytum H, 1992, *The Origins of Early Christian Ireland*, Routledge, London.

O'Kelly MJ, 1952, St Gobnet's house, Ballyvourney, Co. Cork, *Journal of the Cork Historical and Archaeological Society* 57, 18-40.

O'Kelly MJ, 1962, Two ring forts at Garryduff, Co. Cork, *Proceedings of the Royal Irish Academy* 63C, 17-25.

O'Kelly MJ, 1961, The ancient method of smelting iron, in *Internat. Kongress fuer Von u. Fruegeschichte*, Hamburg, 459-91.

O'Riordain SP, 1940, Excavations at Cush, Co. Limerick, *Proceedings of the Royal Irish Academy* 45C, 83-181.

O'Riordain SP and Hartnett PJ, 1943, 'The excavation of Ballycatteen Fort, Co. Cork, *Proceedings of the Royal Irish Academy* 49C, 1-43.

Photos-Jones, E, JA Atkinson, AJ Hall & I Banks, 1998, 'The Bloomery Mounds of the Scottish Highlands. Part 1: the Archaeological Background', *The Journal of the Historical Metallurgy Society*, 32, no 1, 15-32.

Photos-Jones E, 2003, *"If it works, do not fix it":* Early (and Later) Iron working in Ireland along the KEK-M4 Motorway, DRAFT 09/03.

Schubert HR, 1957, *History of the British Iron and Steel Industry*, Routledge & Kegan Paul, London.

Scott BG, 1978, The introduction of non-ferrous and ferrous metal technologies to Ireland: motives and mechanisms, in *The Origins of Metallurgy in Atlantic Europe* (ed M Ryan), Dublin 189-202.

Scott BG, 1983, An early Irish law tract on the blacksmith's forge, *Journal of Irish Archaeology* 1, 59-62.

Schweingruber FH, 1990, *Anatomy of European Woods.* Haupt, Berne & Stuttgart

Sevastopulo GD, 1981, Economic Geology, in *A Geology of Ireland* (by C.H. Holland), Scottish Academic Press, 273-302.

Stace, C 199,. *New Flora of the British Isles* 2nd Ed. Cambridge University Press.

Tylecote, RF 1962, *Metallurgy in Archaeology*. Arnold, London.

Tylecote RF, 1986, *The Prehistory of Metallurgy in the British Isles*, The Institute of London.

Waddell G, 1998, *The Prehistoric Archaeology of Ireland*, Galway University Press.

Warner RB 1973 Excavations at Clogher, Co Tyrone, Clogher Record 1973, in Scott 1983.

Walsh F, 2003, Preliminary Stratigraphic Report of site AE23, Killickaweeny, CH.32100, KEK, Contact 3. Irish Archaeological Consultancy Ltd Internal Report.

Young SM, Clark J & Barry T, 1986, Medieval Britain and Ireland in 1985; review of excavations, *Medieval Archaeology*.

Acknowledgements

We are indebted to Fintan Walsh and John Harrison of IAC Ltd, Dublin, Ireland for their valuable assistance. The author wishes to thank Gert Petersen, Rocio Riuz-Nieto, Sarah Phillips and Robert Macdonald for IT and technical support. Dr R E Jones for much welcome assistance with PCA and DA statistical packages.

Appendix A

Table 3				
Slag: size and weight				
SAE No.	**<5cm**	**<10cm**	**Other**	**Weight**
23.209/SL	X			195
		X		177
23.209/SL				372
23.210/sl	X			280
23.205/sl	X			4
23.204/SL	X			12
23.206/SL	X			14
23.187/SL	X			113
23.188/SL	X			16
		X		49
				65
23.189/SL	X			175
		X		164
				339
23.192/SL	X			48
		X		102
				150
23.190/SL	X			18
23.202/SL	X			372
			15x11x5	583
			11x10x4	306
			12x8x4	318
				1579
23.182/SL	X			105
23.203/SL	X			222
23.208/SL	X			608
		X		239
			13x9x4	206
				1053
23.193/SL	X			649

SAE No.	<5cm	<10cm	Other	Weight	
23.207/SL	X			70	
			13x7x5	365	
				435	
23.201/SL	X			166	
		X		202	
				368	
23.186/SL	X			58	
			14x10x6	712	
			11x11x5	410	
				1180	
23.199/SL	X			5	
23.200/SL			12x10x5	463	
23.198/sl	X			21	
23.180/SL		X		146	
23.196/SL		X		105	
23.179/SL	X			94	
23.185/SL	X			312	
23.184/SL	X			26	
23.184/SL	X			44	
				70	
23.175/SL		X		321	
			14x13x6	899	
				1220	
23.174/sl	X			96	
23.173/SL	X			121	
23.172/SL	X			52	
23.171/SL	X			31	
23.170/SL	X			20	
23.169/SL	X			6	
23.168/SL	X			34	
23.167/SL	X			18	
23.166/SL	X			53	

SAE No.	<5cm	<10cm	Other	Weight	
23.165/SL	X			81	
23.191/SL	X			77	
23.197/SL		X		156	
23.194/SL		X		537	
23.178/SL		X		251	
23.181/SL			14x10x6	778	
23.195/SL	X			32	
23.211/SL	X			15	
23.110/SL	2/2 X			1025	
23.110/SL	1/2 X			905	
				1930	
23.176/SL	X			385	
		X		380	
23.95/SL	(1/2)			376	
	7				
23.73/SL	X			135	
		X		232	
23.72/SL	X			534	
		X		269	
23.71/SL	X			146	
		X		292	
23.79/SL	X			3	
23.83/SL	X			63	CERAMIC
23.77/SL		X		264	
23.75/SL		X		383	
23.74/SL	X			188	
		X		123	
23.85/SL	X			139	
23.84/SL	X			46	
23.80/SL	X			14	
23.81/SL	X			44	
23.78/SL	X			38	
23.76/SL	X			37	
23.87/SL	X			56	
23.86/SL	X			25	
			11X9X5	367	
23.88/SL	X			196	
		X		92	

SAE No.	<5cm	<10cm	Other	Weight	
			14X10X5	483	
				771	
23.91/SL	X			623	
		X		163	
				786	
23.89/SL			12X10X5	466	
23.92/SL	X			41	
23.93/SL	X			17	
		X		84	
			13X12X7	824	
				925	
23.90/SL		X		182	
23.96/SL	X			25	
			13X11X4	447	
				472	
23.82/SL(2/2)	X			345	
		X		1065	
			19X15X9	1274	
				2684	
23.105/SL	X			17	
23.103/SL	X			28	
23.102/SL	X			12	
23.98/SL	X			293	
23.94/SL	X			17	
23.99/SL	X			39	
		X		607	
				646	
23.95/SL			12X9X5	649	
23.101/SL	X			244	
23.104/SL	X			17	
23.100/SL	X			176	
		X		108	
23.142/SL	X			1	
23.161/SL	X			32	
23.160/SL	X			24	
23.163/SL	X			264	
23.157/SL	X			53	
23.162/SL	X			11	
23.144/SL	X			24	
23.155/SL	X			10	
23.135/SL			12X11X5	618	
23.133/SL	X			147	
23.134/SL	X			107	
		X		88	
23.136/SL	X			105	
			16X10X9	878	
				983	
23.156/SL	X			2	
23.159/SL	X			133	
23.164/SL	X			42	

SAE No.	<5cm	<10cm	Other	Weight	
23.153/SL	X			19	
23.150/SL	X			8	
23.143/SL	X			10	
23.141/SL	X			7	
23.147/SL	X			5	
23.152/SL	X			37	
23.149/SL		X		192	
23.151/SL	X			55	
		X		229	
				284	
23.148/SL	X			2	
23.158/SL	X			123	
23.119/SL	X			122	
23.123/SL	X			82	
		X		200	
23.121/SL	X			26	
23.120/SL	X			67	
23.146/SL	X			2	
23.122/SL	X			10	
23.145/SL	X			37	
23.124/SL	X			149	
		X		383	
				532	
23.126/SL	X			125	
		X		380	
				505	
23.125/SL	X			1182	
		X		830	
				2012	
23.131/SL	X			98	
23.154/SL	X			74	
23.140/SL	X			3	
23.139/S/	X			77	
23.138/SL	X			35	
			16X13X9	843	
				878	
23.137/SL	X			84	
			12X10X7	659	
				743	
23.118/SL				41	
		X		319	
				360	
23.132/SL	X			288	
		X		337	
			12X12X4	737	
			14X8X5	311	
				1673	
23.111/SL		X		75	
23.106/SL	X			68	
23.107/SL	X			504	

SAE No.	<5cm	<10cm	Other	Weight	
23.108/SL		X		263	
23.109/SL		X		405	
23.115/SL	X			13	
23.112/SL	X			58	
23.113/SL	X			16	
23.114/SL	X			27	
23.116/SL		X		457	
23.127/SL	X			96	
			12X10X7	601	
				697	
23.129/SL		X		322	
23.117/SL		X		285	
23.128/SL	X			285	
		X		174	
23.130/SL	X			49	
		X		110	CTX710/606
23.57/SL(1/6)	X			752	
		X		101	
23.57/SL (2/6)	X			490	
		X		366	
23.57/SL (3/6)	X			703	
		X		271	
23.57/SL (4/6)	X			538	
		X		514	
23.57 (5/6)	X			3	
				51	
		X		498	
23.57/SL (6/6)	X			421	
		X		413	
23.63/SL;			18X12X9	873	
23.63/SL (1/3)	X			780	
		X		800	
23.63/SL (2/3)	X			410	
		X		405	
			12X8X7	487	
			12X9X5	224	
23.59/SL (1/2)	X			117	
23.59/SL(2/2)	X			285	
		X		403	
23.58/SL (1/5)	X			1168	
		X		1276	
23.58/SL(2/5)	X			346	
		X		834	
			11X8X7	508	
			12X9X5	225	
			13X13X6	49+7	
23.58/SL	X			835	
		X		461	
23.58/SL (4/5)	X			720	
		X		79	

SAE No.	**<5cm**	**<10cm**	**Other**	**Weight**	
23.58/SL (5/5)	X			1525	
		X		563	
23.41/SL	X			321	
		X		1161	
			12X7X4	260	
			14X12X3	512	
23.54/SL	X			1221	
		X		87	
			14X11X7	509	
23.50/SL					
	X			1389	
		X		3818	
23.53/SL	X			1385	Frothy
		X		1720	
			14x12x6	624	
23.55/sl	X			224	
		X		266	
			18X12X10	970	
23.61/SL	X			275	Wood incl.
23.70/sl	X			52	mag. Resp.
23.64/SL	X			66	
23.60/SL	X			121	
23.69/SL	X			116	
23.62/SL	X			660	
		X		156	
23.67/SL	X			118	
23.66/SL	X			124	
23.65/SL	X			83	
		X		432	
23.68/SL	X			21	
23.52/SL	X			144	
		X		418	
			17X15X9	848	