Iron and its alloys in the fifth to eleventh centuries AD in England

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Introduction

The number of iron artefacts recovered from archaeological excavations of settlement sites in England is far lower in the post-Roman period than in the Romano-British period. This trend is observed in other technologies, and there is a general acceptance of an associated decline in technological expertise. This paper will briefly examine the evidence for ironworking during the 5th–11th C. in England and compare it with the evidence provided by the metallurgical analyses of iron artefacts. In this paper 'pre-Conquest' refers to the whole of the time from the end of the Romano-British period to the Norman Conquest and is used to avoid differentiating between terms such as Saxon and Viking.

The ironworking process

The method of manufacturing iron artefacts in England, until the fourteenth/fifteenth centuries AD, was a two-stage process. Firstly, the iron was extracted from the ore by a smelting process known as the direct process, and then it was made into artefacts in the smithing process, which also included the alteration, repair and recycling of artefacts. Both processes generated slag as by-products, and they have been discussed in detail elsewhere (McDonnell 1986:19–26; Tylecote 1986:128–31).

The sources of process data available to the archaeometallurgist are the smelting and smithing slags and the artefacts. The difficulties in recognising the different slag types, and in obtaining meaningful chemical and mineral analyses have been discussed elsewhere (McDonnell 1986:194–224; McDonnell 1988a:122–7; Freestone 1988:49–51; McDonnell forthcoming). There are also difficulties in interpreting the wider aspects of the processes, e.g. the changes in technology, both spatial and temporal, due to the few sites that satisfy the requirements of good excavation, good dating/stratification, and detailed analyses. The evidence of ironworking in pre-Conquest England is particularly sparse and contradictory.

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The archaeological evidence for ironworking in pre-Conquest England

The smelting evidence

Very few pre-Conquest iron smelting sites have been identified in England. Recently several have been excavated but no coherent pattern has emerged. At present there is an almost complete absence of smelting sites in regions such as the Weald (Sussex) and the Forest of Dean (Gloucestershire) which were centres of iron smelting in the Roman and medieval periods. The excavated sites and other evidence occur in areas outside these centres, and fall into two groups, distinguished by different slag morphologies (and hence furnace technologies). The first group includes sites which have slag morphologies that are known in other periods, i.e. they are essentially indigenous. These include tapped slags (e.g. Stamford, Mahany et al. 1982:133–44), raked slags (Millbrook, Tebbutt 1982:19–36) and furnace slags (Ramsbury, Haslam 1980:1–68). The total number of excavated sites that can be satisfactorily attributed to this group is about ten. Smelting slag has been recorded from a number of other sites but either it has not been examined in detail or the dating evidence is poor, e.g. the possibility of residual Roman iron smelting slags. On the second group of sites the slag has a distinct morphology termed slag block (*Schlackenklotz*) which represents a technology common in southern Scandinavia, north Germany and Poland. In England the distribution is tentative due to the low number of examples, but to date they have been found in eastern England from Lincolnshire in the north to Hampshire in the south, with a high concentration in East Anglia. Slag blocks have been recorded on three excavations – Romsey, Hants (McDonnell 1988b), Mucking, Essex (M.U. Jones pers. comm.) and Little Totham, Essex (Cranstone 1988:4); the other examples are surface finds. At present the dating of Romsey is tentatively post-Roman but recent C14 and TL dates from Little Totham have produced dates of sixth/seventh centuries AD (1988:4). These limited data show that an apparently intrusive smelting technology appeared in the early Anglo-Saxon period on the English eastern seaboard. It is tempting to link the appearance of the new technology with the arrival of the Germanic immigrants at the end of the Roman period, but there is as yet insufficient evidence to prove this.

The smithing evidence

Most settlement sites (from the Iron Age onwards) produce some evidence of smithing. This is to be expected, since smithing would be required to manufacture and repair iron artefacts used by the communities, but the number of identified blacksmiths' workshops in any period is very low. There were different levels of smithies, i.e. from permanent 'full-time' workshops to forges where occasional smithing operations were carried out. The different types of workshop might have practised different types of smithing ranging from specialist smiths, e.g. cutlers, to general smithing.

The evidence from this period is sparse, and although there are numerous finds of iron smithing slags in pre-Conquest contexts very few smithies have been identified (defined for these purposes as a workshop/building with associated smithing slag). Smithies have been excavated in both urban and rural contexts but the number of sites is too small (less than ten) to justify undertaking detailed comparisons. Urban smithies have been identified at Hamwih, Southampton (seventh to ninth centuries AD, Andrews forthcoming) and at Coppergate, York (AD 850–1100, Ottaway forthcoming). Examples of rural smithies are Wharram Percy, East Yorkshire (c.seventh century AD, McDonnell 1985) and Gauber. High Pasture, Ribblehead, North Yorkshire (ninth to tenth centuries AD, King 1978:31–6). The Wharram Percy smithy was probably a 'village' smithy, whereas the Gauber example belonged to a farmstead and represented only occasional smithing activity.

The metallurgy of pre-Conquest iron artefacts

The metallurgical analysis of iron artefacts, in particular edged tools, from Hamwih (McDonnell in Andrews forthcoming), Coppergate (McDonnell in Ottaway forthcoming) and other sites (e.g. Winchester, v. Tylecote and Gilmour 1986:3–18) has demonstrated that smiths had four types of iron available for use. It should be noted that all the irons contain slag inclusions, to a greater or lesser extent, and that the term 'wrought iron' is not used because, in effect, all the direct process irons, i.e. pre-blast furnace, were 'wrought'. The irons used were:

1 Ferritic iron

Ferritic iron contained no (<0.1 per cent) alloying elements, i.e. it was pure iron. It occurs most commonly as a component of piled or banded structures (see below). The metallographic analyses suggest that ferritic iron was more common in the artefacts from Hamwih than those from Coppergate.

2 Phosphoric iron

Phosphoric iron contained between 0.05–0.5 per cent phosphorus as an alloying element, (Plate 1). The majority of British iron ores contain phosphorus, and during the reduction process it was concentrated in the metal. The effect of phosphorus in iron is two-fold in that it inhibits carbon diffusion, thus preventing the production of steel, and it increases the hardness of the ferrite, embrittling the iron. It is, therefore, regarded as detrimental in modern day metallurgy, but might be construed as advantageous in early times, because of its hardening properties. The metallographic evidence suggests that it was the commonest form of carbon-free iron at Coppergate (Phase 4), and was present as a component in most of the artefacts.

3 Steel

Steel contains carbon as the main alloying element and was used to manufacture the cutting edges of tools. The metallographic analyses indicated the use of hypo-eutectoid

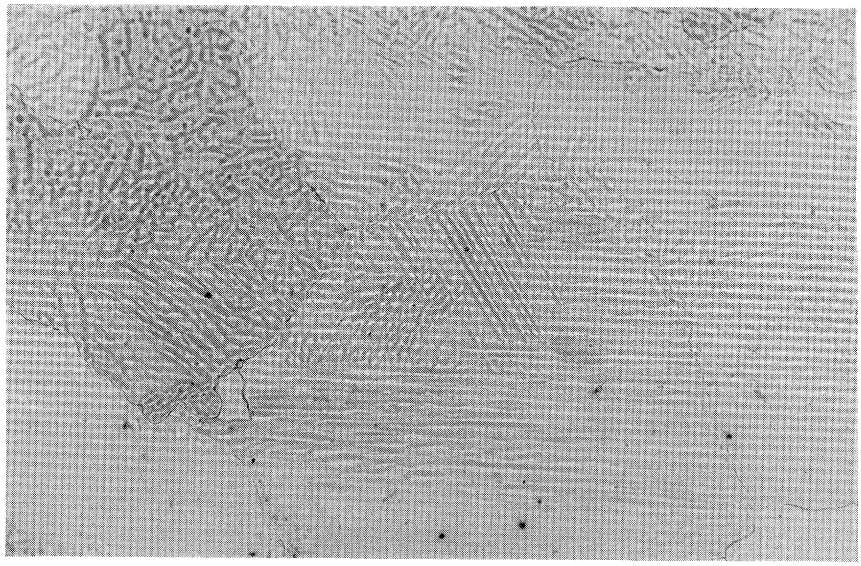

Plate 1 Phosphoric iron showing ghost Widmanstätten-like structures within the grain boundaries. (Etchant – nital; magnification x70.)

steels (i.e. steel containing less than 0.8 per cent carbon), although carbon contents did vary widely within samples and between samples. The increased hardness in cutting edges was obtained not just by additional carbon content, but by deliberate heat-treatment so that quenched and slack-quenched structures in the as-quenched or tempered condition were produced.

4 *Piled and banded structures*

The term piled or banded structure refers to metallographic structures in which alternating bands of different irons are present. The thickness of the bands may vary from a single grain upwards, and the number of bands also varies. The bands can comprise combinations of: ferritic iron/phosphoric iron, ferritic iron/steel, phosphoric iron/steel. It is not possible to determine whether or not the piled structures were the result of deliberate manufacture, i.e. the welding together of strips of different compositions. Such structures may also have been accidentally generated by the segregation of either phosphorus or carbon during the smelting process and the subsequent refining of the bloom. The analyses of the artefacts indicate that piling became more common in the later phases at Coppergate.

Pattern-welding can be considered a coarser form of piled structure. In this process strips of iron (normally of different types) were welded and twisted or folded together. Pattern-welding differs from piled structures in that the banding was much coarser so that the differences between the metals, often enhanced by etching, were intended to form a decorative design on the surface of the finished object. The techniques of pattern-welding and its occurrence are discussed in detail by Gilmour (Tylecote and Gilmour 1986:250–4).

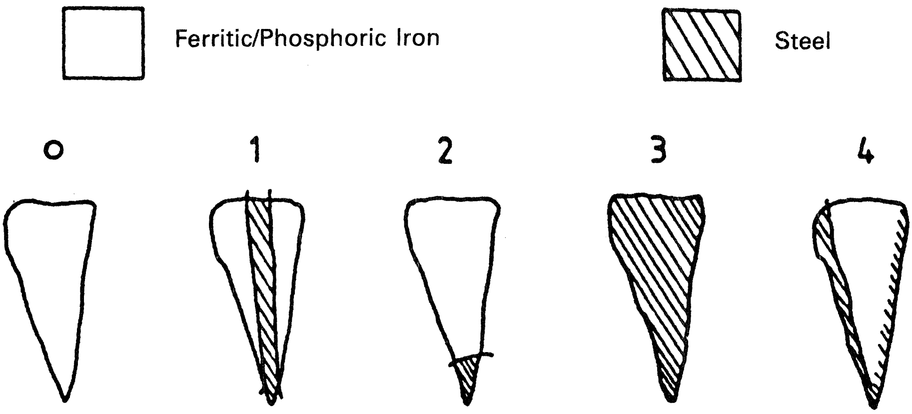

Figure 1 Knife manufacturing typology (after Tylecote and Gilmour 1986).

In different periods the types of iron used differed and their method of use varied, but in general steel (annealed or heat treated) was used for the cutting edges and the ferritic, phosphoric and piled structures were used to manufacture the remainder of the artefact. Constructional and decorative artefacts would use the most easily available/ cheapest iron. This was confirmed by the analysis of a range of hooks, eyes, staples etc. from Coppergate which were predominantly phosphoric iron. The metallurgical analysis of the artefacts enables the quality of iron used and the smithing skills employed to manufacture that artefact to be assessed.

The group of artefacts most suitable for analysis in knives. There are several reasons for this: firstly, knives are a reasonably common find on archaeological sites, and therefore statistically significant numbers can be sectioned; secondly, they can be ascribed to a typological series; and thirdly, there were five basic methods of knife manufacture (Figure 1, after Tylecote and Gilmour 1986:6) so that correlations between quality, typology and method of manufacture can be investigated.

There are some difficulties with knives (or any iron edged tool); in particular repair

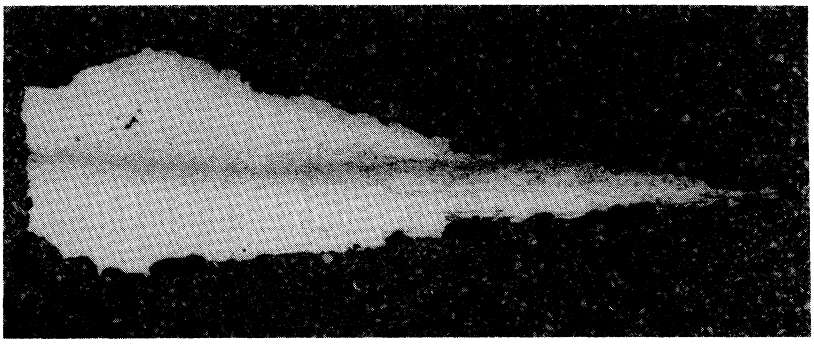

Plate 2 Arrowhead of Type 1 manufacture showing migration of cutting edge away from the steel core. (White – ferritic/phosphoric iron; dark etching band pearlitic steel. Etchant – nital; magnification x14.)

Table 1 Mean and standard deviations of hardness results (after Tylecote and Gilmour 1986:20–1, 29, 38–9).

Period/Date	*Number of measurements*	*Mean HV*	*Standard deviation*
Romano-British	18	270	131
5th–10th Centuries	12	463	198
11/12th Centuries	14	373	189
13th Century or later	14	363	154
14th Century or later	11	343	147

Note: In all Tables the number of measurements refers to the number of cutting edges measured.

or re-working of the blade can alter its quality, and accidental treatments, e.g. loss in a domestic hearth, may also change its micro-structure. Corrosion or heavy wear can remove cutting edges, in particular butt-welded knives (Type 2) can loose their edge and appear to be 'edgeless' knives (Type 0). The date of a context in which a knife is found is a *terminus ante-quem* date for that knife, and it should not be used as a date of manufacture. The evidence of wear on some knives indicates that they were in use for long periods. Metallurgical evidence shows that mis-sharpening of a blade may cause the cutting edge to migrate away from the steel embedded for that purpose (Plate 2). Type 1 knives are particularly prone to this effect.

The measurement of the hardness of a cutting edge is the most suitable method for quantifying the quality of the metal. Table 1 gives the mean and standard deviations of the hardness values obtained for cutting edges of knives from several periods and sites by Tylecote (Tylecote and Gilmour 1986). This shows a significant increase in the fifth to tenth centuries with a slight peak in the ninth/tenth centuries and then a slight decline in the medieval period. The Romano-British/post-Roman change would be demonstrated more clearly if one knife (Knife 707253 from Wanborough, table 6 p. 29) was accepted as mis-dated due to its very high hardness (720 HV). The Romano-British values would then be: mean = 243; standard deviation = 77. This change, i.e. the greatly increased edge hardness, is due to the application of heat treatments to steels (i.e. quenching and tempering) in the post-Roman periods.

Table 2 Mean and standard deviation hardness results from Hamwih and Coppergate.

Site/Date	*Number of measurements*	*Mean HV*	*Standard deviation*
Hamwih (6–9thC)	14	477	207
Coppergate			
Phase 3 AD 850–925	8	628	250
" 4 AD 925–975	19	474	231
" 5 AD 975–1066	17	333	228
" 6 medieval	5	323	166

Table 3 Variation in manufacturing typology.

Site/Date	*Number of measurements*	*Manufacturing typology* 0	1	2	3	4	*Total*
Hamwih (6–9th.C)	14	1	1?	11	1	–	14
Coppergate							
Phase 3 850–925	8	–	1	5	2	–	8
" 4 925–975	19	2	7	6	2	2	19
" 5 975–1066	17	2	12	3	1	–	18
" 6 medieval	5	1	3	–	1	–	5

(Total = the total number of knives examined.)

More recent results (Table 2) obtained for closely dated knives from Hamwih and Coppergate confirm the use of heat treatments in pre-Conquest times, but also suggest that there may have been changes within the period itself, both of quality and method of manufacture. This Table also confirms an apparent peak of hardness in the ninth century which was suggested by Tylecote's data which were from only three artefacts.

The changes in smithing techniques can also be examined by observing any changes in manufacturing typology (Fig. 1) with date. The results from Hamwih and Coppergate (Table 3) demonstrate the predominance of butt-welded knives (Type 2) at Hamwih and in the earliest phase at Anglo-Scandinavian York. Thereafter, at York, knives were manufactured in more varied ways, but with a predominance of Type 1. (N.B. the discrepancy between the number of measurements (17) and the total number of knives (18) in Coppergate Phase 5 is due to the cutting edge of one knife being so heavily corroded that no measurement of hardness could be obtained.)

Further, there is a strong correlation between Type 2 manufacture and high hardness (Table 4), which is most pronounced in the Coppergate data when compared with the results from the Type 1 knives. This correlation (and the overall high hardness at Hamwih and Coppergate, Phase 3) could be explained by the need for Type 2 knives to have their cutting edges replaced when they had worn through the steel into the iron back. The Type 1 knives continuously exposed new steel as they were worn back; thus they could wear through the initial quenched and tempered edge into more heavily tempered (less hard) steel. This loss of effectiveness in the cutting edge could easily have been rectified by secondary heat treatment. There is no evidence to indicate that this was undertaken to any great extent, and therefore it can be assumed that the quality of tool maintenance was generally low.

Table 4 Mean hardness values and standard deviations of Type 1 and 2 knives.

	Coppergate			*Hamwih*		
	Total	*Mean*	*S.D.*	*Total*	*Mean*	*S.D.*
Type 1 Knives	22	377	211	1	–	–
Type 2 Knives	14	623	240	11	482	228

Summary of the metallographic evidence

The metallographic analyses so far carried out on pre-Conquest iron knives demonstrate that there was a significant improvement in blacksmiths' skills over those of their Romano-British counterparts, characterised by the use of heat treatments. There is evidence for a slight decline in smiths' skills in the early part of the tenth century, which continued on into the medieval period.

Discussion

There is a dichotomy between the archaeological evidence for ironworking in pre-Conquest England and the metallographic evidence obtained from analyses of iron artefacts, particularly knives. From the archaeological evidence for iron smelting three conclusions can be drawn. Firstly, that there are disproportionately fewer iron smelting sites in the 5th–11th centuries, when contrasted with other periods. Secondly, that there is an apparent absence of smelting activity in areas known to have been extensively worked in the Romano-British period (and Iron Age) and which were also exploited in the medieval period. Thirdly, that two broad traditions may be observed in the few sites that have been investigated. These are the indigenous smelting technologies that were present in earlier periods, and an intrusive technology (slag block or *Schlackenklotz*), that at present has a (south) eastern seaboard distribution, perhaps associated with 'Germanic' settlers. The overall interpretation of the smelting evidence is of local production to fulfil local needs.

The archaeological evidence for smithing is also sparse, as despite widespread occurrence of 'smithing debris', very few smithies have been recognised. Those that have been excavated suggest a wide range of types from urban, full-time smithies to small forges or workshops on a farmstead site. This would appear no different from the archaeological evidence available at present of smithies in the Roman or medieval periods.

The metallographic evidence, on the other hand, suggests that during the 5th–11th centuries in England the highest level of smithing skill was achieved, above that of the Iron Age, Romano-British or medieval periods. The evidence also points to a slight decline in skills towards the end of the period, which is accompanied by the increased use of different methods of knife manufacture, particularly Type 1. This pattern is continued into the medieval period.

Conclusions

The above discussion demonstrates that there is a conflict of interpretation between the archaeological evidence for iron smelting and the metallographic evidence from the artefacts. The occurrence of 'smithing debris', but few identified smithies, would accord with the evidence from other periods and supports the widespread use of iron in the

5th–11th centuries. The problem that needs to be resolved is the method of production of the iron and steel.

Several explanations can be offered, for example recycling of Romano-British iron, or importation of significant quantities of iron, but they contradict the evidence already available (high quality steel could not easily be obtained from scrap iron, and there is evidence for an imported smelting technology). Therefore the primary archaeological evidence for iron smelting must be examined, and in particular attention focused on the areas that were centres of iron production in other periods.

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Abstract

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Iron and its alloys in the fifth to eleventh centuries AD in England

This paper discusses the evidence for iron smelting and iron smithing in pre-Conquest England. It contrasts this evidence with the results obtained by metallurgical analyses of iron knives dating to this period. These analyses show that the smiths of the period had four different irons to select from, and were expert in their use and in the heat treatments of steel. The dichotomy between the paucity of iron smelting evidence and the skill of the blacksmiths is investigated.