Ancient Monuments Laboratory
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A TECHNOLOGICAL STUDY OF FERROUS BLADES FROM THE ANGLO-SAXON CEMETERIES AT BOSS HALL AND ST STEPHEN'S LANE - BUTTERMARKET, IPSWICH, SUFFOLK

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Summary

The X-radiographs of forty-five knives, eleven spearheads and three seaxes were examined for features which suggest the methods of construction of the ferrous blades. Three spearheads were examined by metallography and were found to be poor in quality. The majority of the other blades are too corroded to provide metallurgical data or have fragile mineralised organic remains which precluded sampling for metallographic examination.

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A technological study of ferrous blades from the Anglo-Saxon cemeteries at Boss Hall and St Stephen's Lane – Buttermarket, Ipswich, Suffolk

Vanessa Fell and David Starley

The ironwork assemblage from Boss Hall includes twenty-two knives and nine spearheads. All were found in graves dated to the sixth century with the exception of one fragment of a blade from Grave 93, which is of late seventh century date. The twenty-three knives, two spearheads and three seaxes from Buttermarket are all from seventh century graves. All of these blades are from inhumations.

The purpose of this study was to investigate the technology used in the manufacture of the knife blades and spearheads. Previous studies have shown the high degree of skill used by Saxon ironworkers in constructing knives and edged weapons (eg Tylecote and Gilmour 1986). Questions that may be addressed are:

- Which metals were chosen? Three main ferrous alloy types were used in the Saxon period. **Ferritic** iron – a soft and easily worked metal. **Phosphoric** iron – an alloy of iron with very small amounts of phosphorus making it slightly harder. **Steel** – an alloy of iron and carbon which is not only harder and stronger but can be further hardened by quenching.
- How were different alloys were combined in a composite blade so as to give the best overall properties? For example there are a number of ways in which a hard steel edge can be welded onto a softer, tougher blade back.
- To what extent was the metal worked? Techniques such as piling, in which the metal is repeatedly hammered out, folded over and welded together, were used to produce a more homogenous product.

● Were heat treatments used to modify the metals' properties? Techniques such as annealing allow easier working of the metal, whilst quenching and tempering give enhanced properties to steel in the finished artefact.

● Is there any evidence of changes subsequent to manufacture? Was Boss Hall spearhead 87/2, which when found had a 90 degree bend at the neck, heated to facilitate this?

These questions can most effectively be answered by examining the microstructure of the metal, where composition and heat treatment histories are manifested as specific crystalline phases. This can be undertaken using the technique of metallography in which samples are cut from the artefact, polished and etched to reveal the crystal structure when viewed with an optical microscope.

X-radiographs had been made of the blades soon after excavation, sometimes initially in soil blocks, and subsequently during conservation and post-excavation examination and analysis (at Norfolk Museums Service and at the Ancient Monuments Laboratory). These X-radiographs were examined prior to any metallography, firstly to assess the suitability of the blades for sampling and secondly to identify technological features. The blades were also visually examined, and tested with a magnet to determine the extent to which the metal survived beneath the corrosion layers.

Tables 1 and 2 detail the results of assessment of the blades, based on their X-radiographs, visual examination of the objects, and their response to a magnet. Three knives from Buttermarket were unavailable for visual and magnetic examination. The X- radiographs suggest that some blades have complex metal constructions such as weld lines associated with composite constructions. Intricate layers of mineralised organic materials, such as sheaths and wrappings were also apparent. The latter sometimes survive to several millimetres in thickness, although usually only intermittently.

Unfortunately most of the blades were found to be too corroded to provide metallurgical data. Furthermore, where mineralised organic remains survived the possibility of damage by sampling was unacceptable. Three spearheads (Table 3) from Boss Hall were successfully sampled for metallography. However, three knives from the same site and one spearhead from Buttermarket (Table 3) were also sampled but found to contain no metal.

Table 1. Boss Hall blades: technological features

Grave	at	SF	Technological features visible in X-radiographs	Magnetic behaviour
nives				
13	3	9;13/F	No features visible (blade in several pieces)	1
13	2	12/F	No features visible	3
51	4	53/F	No features visible	4
74	14	67/F	Weld line near blade back	2
74	19	42/F	Piling or stringers (and metal) clearly visible [sampled]	3
74	21	60/F	Weld line one-third way up blade, possible butt-weld	1
74	22	59/F	Possible weld line half-way up blade (but image confused by organic materials) [sampled]	1 (tang)
74	23	24/F	? Piling (but image not clear)	2
87	12	66/F	No features visible	2
93	3	25/F	— (Blade fragment only; no X-radiograph)	2
95	8	51/F	Piling or stringers in blade back	3
96	8	46a/F	Possible weld line half way up blade	3
97	16	81/F	Some internal structure, ?piling	3
97	17	80/F	Possible weld line half way up blade	3
147	1	70/F	Several weld lines through blade [sampled]	2
150	7	71/F	Complex back; possible welded-in component	1
152	5	85/F	Piling or stringers. ?Metal survives	3
301	26	92;94/F	No features visible	1
313	103	338/F	— (No X-radiograph)	1
315	5	104/F	Piling or stringers in blade back	1
315	7	106/F	?Weld lines	1
u/s	-	88/F	Possibly welded	2
Spea heads				
51	2	21/F	Piling or stringers [sampled]	5
74	6	77/F	Piling or stringers	4
74	8	78/F	Much piling or stringers [sampled]	5
74	9	79/F	Much piling or stringers Metallic regions	4
87	2	19/33/F	Piling or stringers [sampled]	5
95	2	22/F	Central component, plus piling or stringers. Metallic regions. Much textile adhering.	4
96	1	45/F	Piling or stringers. Metallic regions	5
u/s	-	86/F	Much piling or stringers	5
u/s	-	87/F	Piling or stringers. ?Metal at centre but not edges	5

Magnetic behaviour:
0, none;
1, very weak (probably no metal);
2, weak (unlikely to contain any coherent metal);
3, weak (but may contain some metal);
4, strong (probably contains some metal);
5, very strong (likely to contain appreciable metal).

Table 2. Buttermarket blades: technological features

r ave	Cat	SF	Technological featu es visible in X- adiog aphs	Magnetic behaviou
Knives				
968	1	3221/F	Piling or stringers in blade back. Possible weld half-way up blade.	3 (at tang)
968	2	8827/F	Possible weld quarter-way up blade (sheath obscures detail)	0
1306	7	8815/F	No features visible	0
1356	1	8812/F	Probable complex structure but image obscured by mineralisation	1
1356	2	7562/F	No features visible	2
1760	1	4700/F	Possible weld line half-way up blade	1
2339	1	8804/F	No features visible.	? (not seen)
2946	1	6796/F	Weld, towards blade back	2
2962	18	8828/F	Possible weld (blade is corroded to another object, obscuring image)	0
3243	3	8830/F	Probable butt-weld	0
3571	2	7761/F	Weld, possibly pattern-welded	2
3571	2	9047/F	Possible weld	0
3659	2	8971/F	No features visible	1
3871	1	8805/F	No features visible	2
3889	1	7410/F	Possible complex structure	2
4054	1	7314/F	Possible structure	2
4152	1	7306/F	Probable complex structure but image obscured by mineralisation	? (not seen)
4269	1	8257/F	No features visible	2
4275	46	8807/F	Probable weld one-third way up blade	2
4344	2	7667/F	Pattern-welded	2
4543	1	8053/F	? Butt-welded	0
4995	1	8476/F	No features visible; mineralisation obscures image	0
?	?	4601/F	No features visible	? (not seen)
Seaxes				
1306	16	3225/F	No features visible	3
2297	1	6786/F	No features visible	3
3243	4	6795/F	?Inserted component showing bands; possibly pattern-welded	1
Spea heads				
1306	1	3223/F	Piling or stringers	3
1306	6	3226/F	No features visible [sampled]	3

Table 3. Blades sampled for metallography

Site	Grave	SF	AML no.	Sample
Boss Hall	51/2	21	970001	Spearhead blade
Boss Hall	74/8	78	970002	Spearhead blade
Boss Hall	87/2	19	970003	Spearhead blade
Boss Hall	87/2	19	970004	Spearhead neck
Boss Hall	74/19	42	970014	Knife blade (no metal)
Boss Hall	74/22	59	970015	Knife blade (no metal)
Boss Hall	147/1	70	970013	Knife blade (no metal)
Buttermarket	1306/6	3226	-	Spearhead blade (no metal)

Methods of metallographic examination

Two overlapping half-sections were removed from the blade of spearhead 74/8 Δ78 (AML 970002). Single half-sections were removed from the blades of spearheads 87/2 Δ19 (AML 970003) and 51/2 Δ21 (AML 970001). Additionally, Δ19 was sampled through the neck (AML 970004). This spearhead had a 90° bend at the neck, made prior to burial, and this area was investigated to see if the spearhead had been heated to facilitate bending. Sample positions (Figure 1) were selected according to condition on the basis of the X-radiographs.

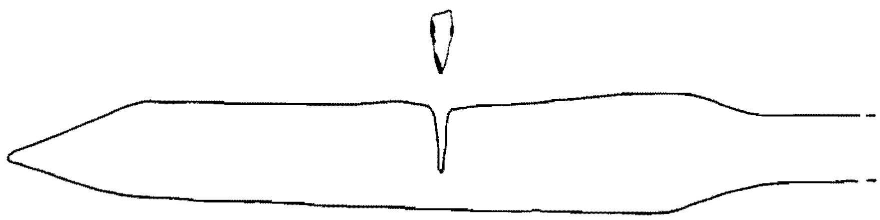
Samples were removed using a low speed cut-off wheel, with a thin (0.25mm) rubber-bonded silicon carbide blade. The sections were mounted in thermosetting phenolic resin. These were ground and polished according to standard metallographic techniques, examined in the unetched condition and after etching with 1% nital (nitric acid in alcohol). Microhardness readings are averaged Vickers Pyramidal values obtained using loads of 0.2kg applied for 30s. Grain size was measured with an eyepiece graticule at x100 magnification. The specimens have not been analysed for elemental composition.

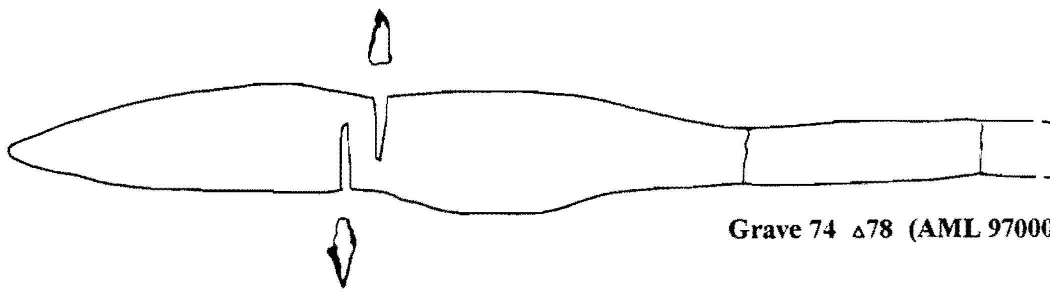
Results of metallographic examination

The results for the spearheads are described separately below and summarised in Table 4 and Figure 2. Samples from the three knife blades contained no metal and no useful data could be extracted. These have not been reported upon. Technical terms are defined in Samuels (1980).

Table 4. Summary of metallographic results for the Boss Hall spearheads

Sample Grave	SF	AML no. (sample)	Microstructure	Carbon %	Hardness HV (0.2)	Grain size ASTM
51/2	21	970001	Ferrite	0 - 0.01	117; 155	1 - 6
74/8	78	970002	Ferrite	0	147; 165	3
			Ferrite + pearlite + Phosphorus 'ghosting'	≤0.05	173 - 208	7
87/2	19	970003	Ferrite	0	138	3
			Ferrite + P 'ghosting'	0	204	2
			Pearlite	≤0.05	116	5
87/2	19	970004	Ferrite	0	186	3
			Ferrite + pearlite	≤0.05	186	7





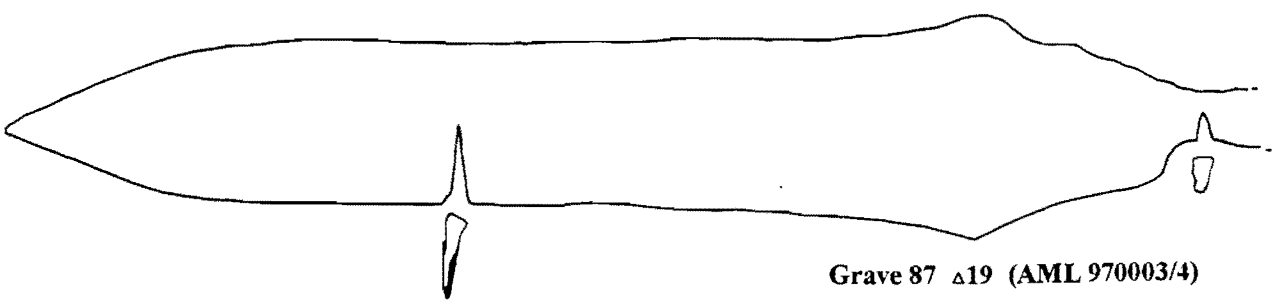


Figure 1. Boss Hall spearheads: sample positions (scale 1:2)

Spearhead: Grave 51/2 △21

Sample
One half-section through the blade at approximately blade centre (Fig 1).
(AML sample no. 970001)

Examination: unetched
Abundant dual-phase non-metallic inclusions are concentrated at the two sides of the section, at one side in particular. These are well-broken, small and not aligned.

Etched
Equiaxed ferrite (Plate 2). Smaller grained at the side with the greater concentration of inclusions (grain size ASTM6); some very large grains at the centre (ASTM 1). There are very slight traces of grain-boundary carbide in the large grained ferrite (away from the inclusions). No evidence of welds and no mottling suggestive of phosphoric iron.

Hardness
Ferrite, large grains at centre: 117 HV(0.2)
Ferrite, smaller grains further away from edge: 155 HV(0.2)

Interpretation
The spearhead seems to have been made from plain iron, the inclusion concentrations suggesting poor smithing of the bloom. There had been no attempt to harden this blade, which was in the relatively soft, annealed condition.

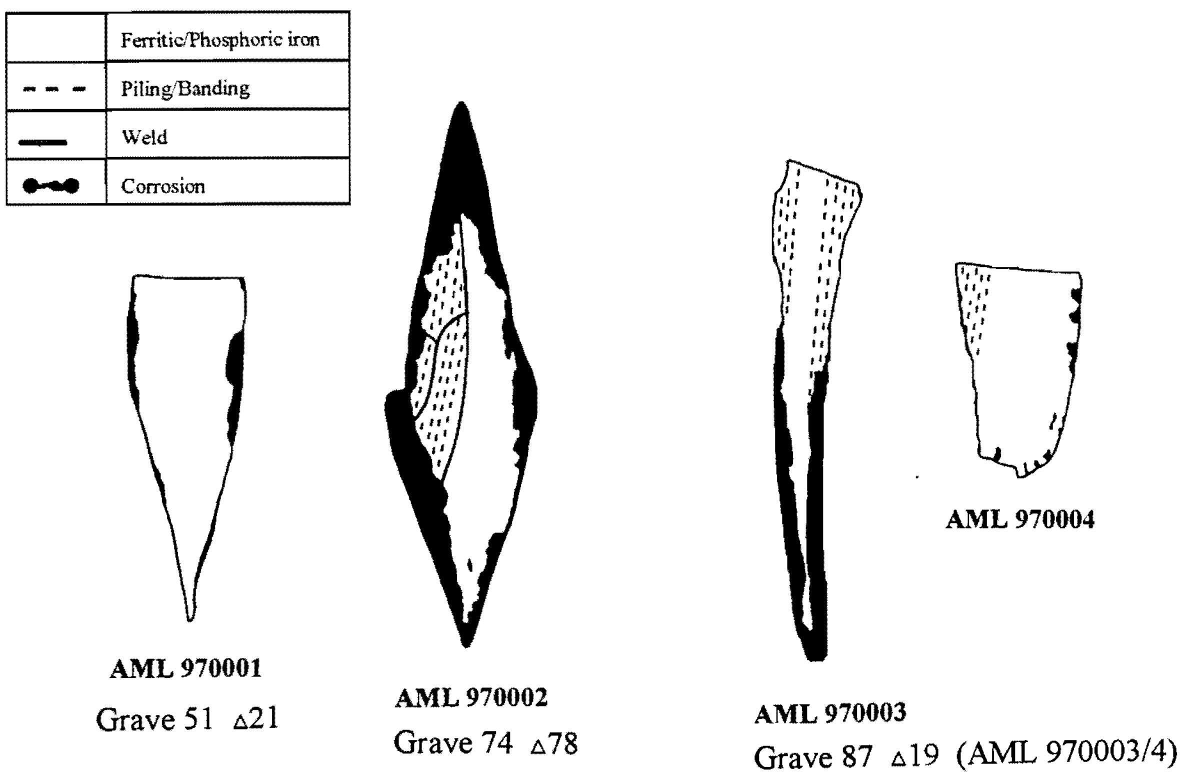


Figure 2. Boss Hall. Details of sections of spearheads (scale 3:1)

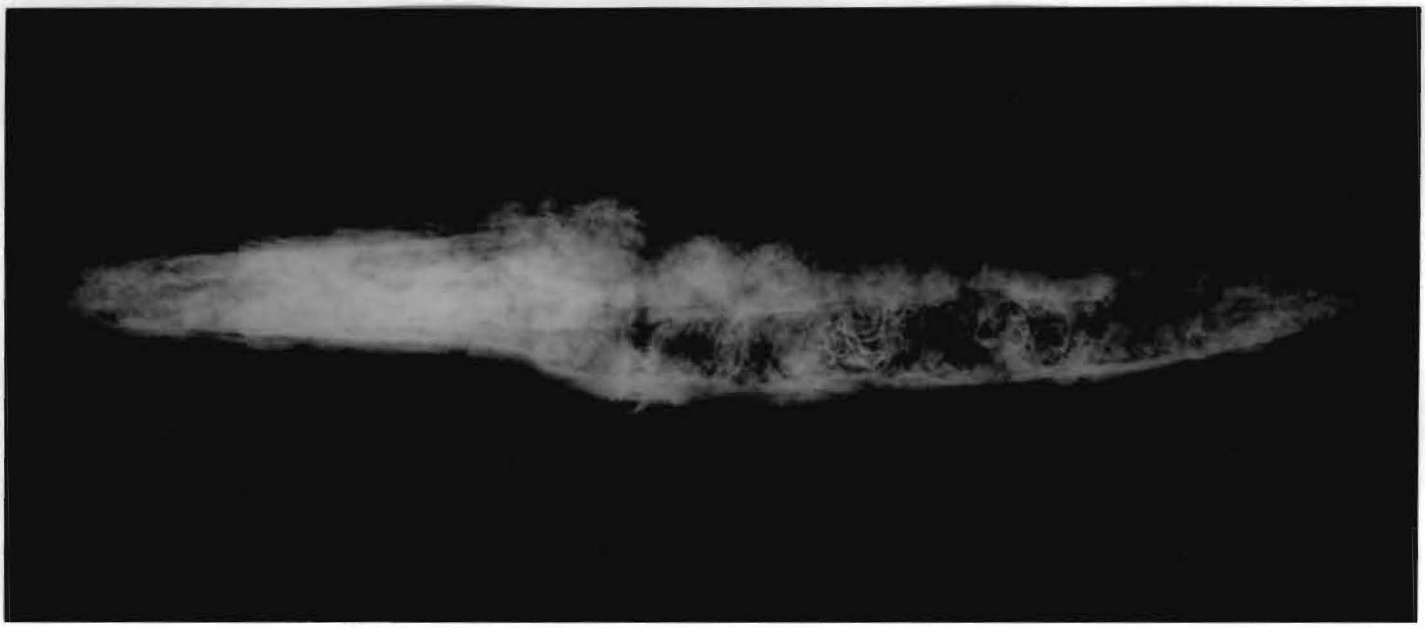


Plate 1. Buttermarket: knife 4344/2 △7667. X-radiograph showing pattern-welded structure. Scale 1:1

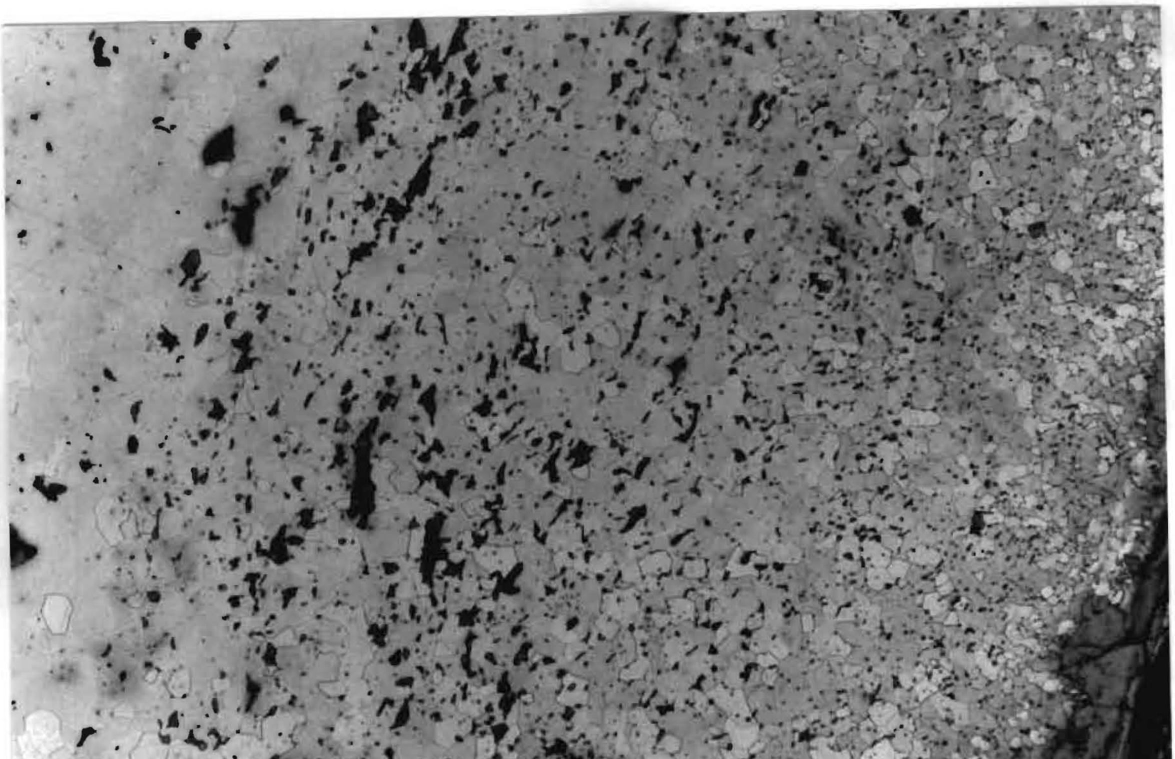


Plate 2. Boss Hall: spearhead 51/2 △21. Structure comprises ferrite of variable grain size, with abundant inclusions (dark) near the smaller grains. x200. Nital etch.

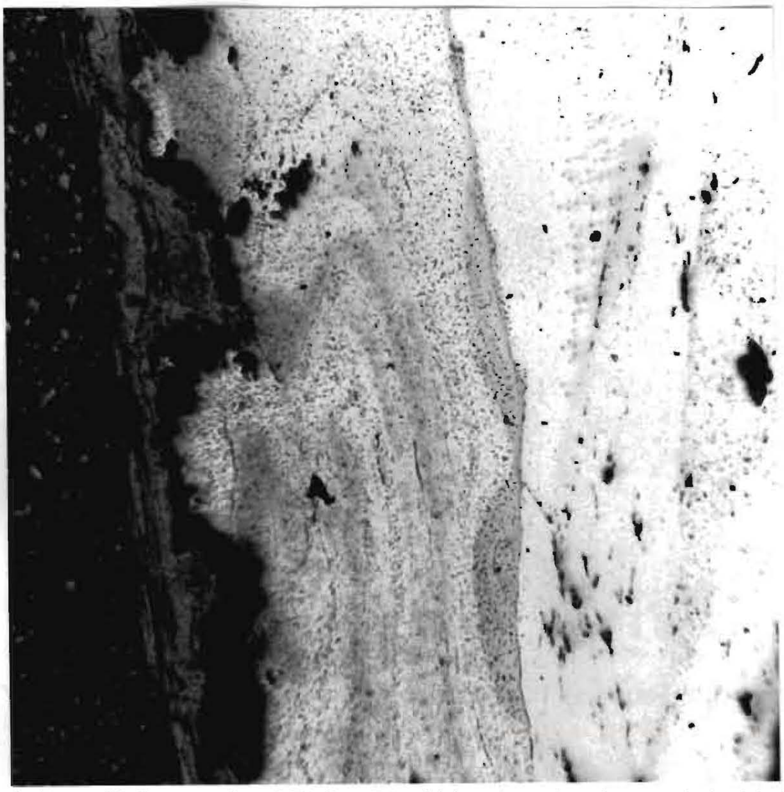


Plate 3. Boss Hall: spearhead 74/8 ▵78. Side of section (centre left side in Fig 2) showing ferrite zone (right, pale) separated by a weld from the carburised zone comprising irregular and curving bands of mottled appearance and probably containing phosphorus (centre, variable grey). x100. Nital etch.

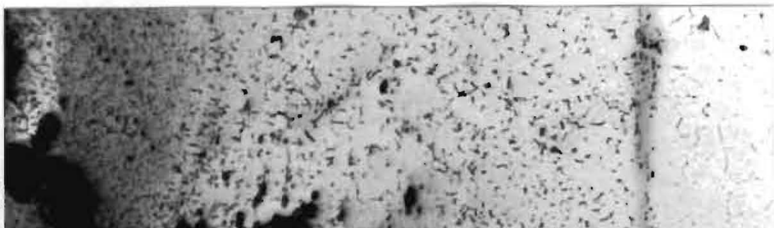


Plate 4. Boss Hall: spearhead 74/8 ▵78. Detail of Plate 3, centre, showing piled and welded structure. Carburised region at centre and left comprises ferrite with pearlite. The bulk of the section (part shown at extreme right) comprises ferrite with traces of grain-boundary carbide x200. Nital etch.

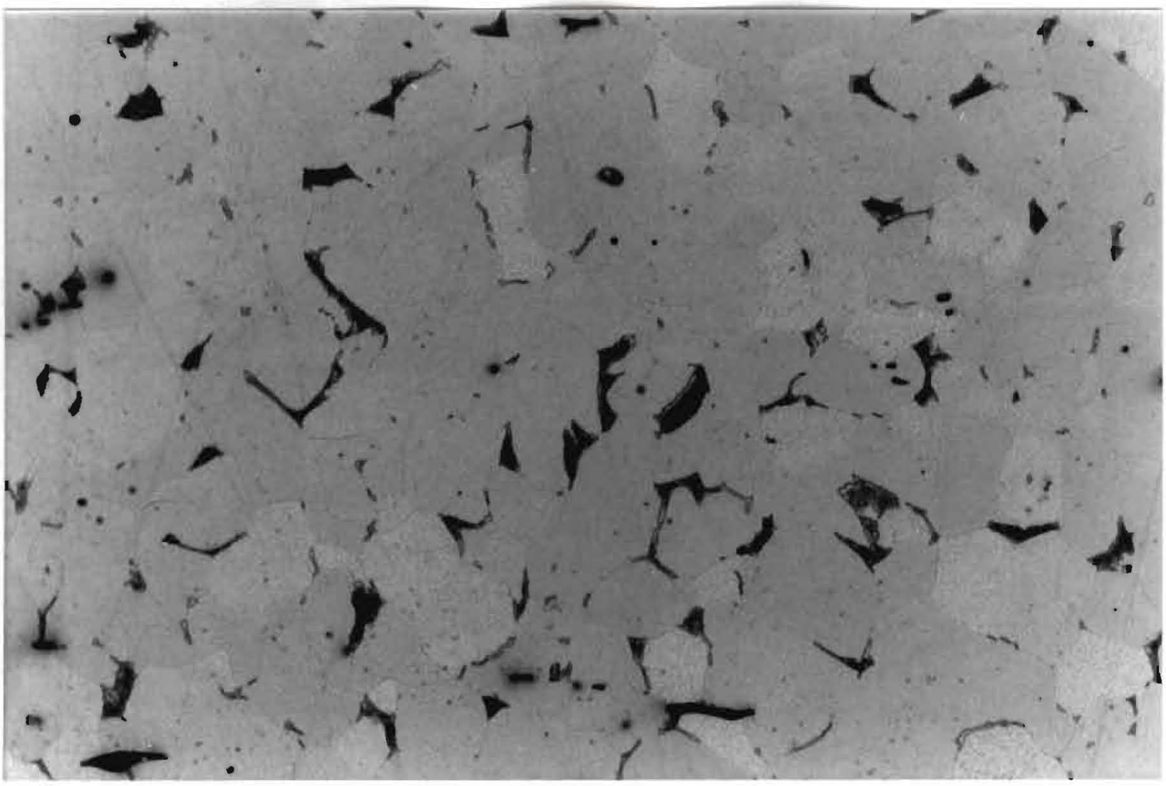


Plate 5. Boss Hall: spearhead 87/2 ▵19, blade. Equiaxed grains of ferrite, with traces of fine pearlite (dark). x1600. Nital etch.

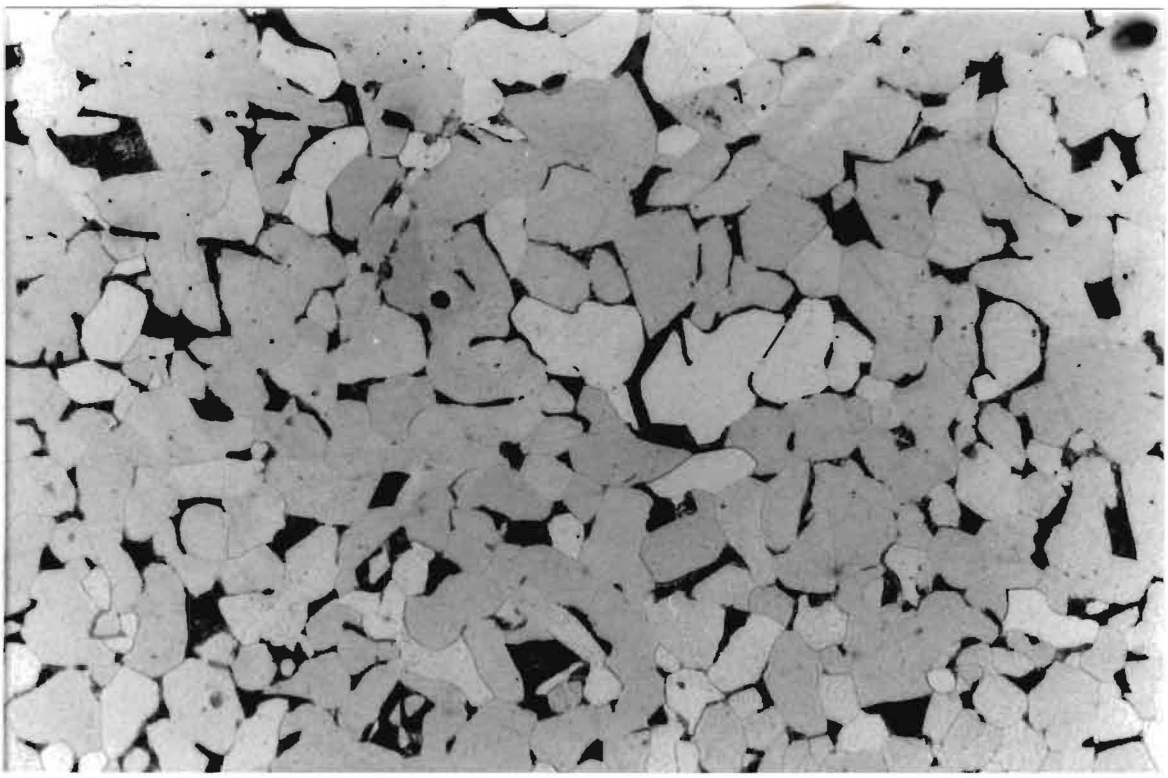


Plate 6. Boss Hall, spearhead 87/2 ▵19, neck. Similar microstructure to the blade

Spearhead: Grave 74/8 ∆78

Samples
Two overlapping half-sections through the blade (Fig 1).
(AML sample no. 970002)

Examination: unetched
There are small quantities of well-broken, angular, multi-phase non-metallic inclusions, most of which are near the centre of the blade. A few particles are aligned, but most are not. There is much corrosion within the metal.

Etched
The sections comprise large-grained equiaxed ferrite (grain size ASTM 3), with zones of smaller grained ferrite (ASTM 7) with traces of carbon (<0.05%C) visible as coarse, grain-boundary pearlite in which the carbide had begun to coalesce. The smaller-grained (carburised) zones, which occur at the two sides of the blade but not at the extreme tips of the blade, have irregular and curving bands of mottled appearance (hardness 173 to 208HV), plus some alignment of inclusions (Plates 3 and 4).

Hardness
<u>Larger section</u>:
Ferrite (large grains) + grain-boundary carbide near the blade edge: 138 HV(0.2)
Ferrite (very large grains) at centre of section: 165 HV(0.2)
Ferrite + pearlite at mottled area near rear of section: 208 HV(0.2)
<u>Smaller section</u>:
Ferrite (large grains) at centre of section: 147 HV(0.2)
Ferrite + pearlite (small grains) with some mottling: 173 HV(0.2); adjacent whiter mottling: 198HV (0.2)

Interpretation
The mottled appearance and higher hardness of some of the ferrite suggests that phosphoric iron is a major component, even where carbon is present in the structure and the grain size is small. The mottled, carburised zones are clearly delineated in places, which suggests that bulk metal of differing compositions has been forged together and piled. There seems to have been no attempt to enhance the quality of the blade through carburisation and quenching, or by use of phosphoric iron or steel at the blade edges.

Spearhead: Grave 87/2 Δ19

Samples
One half-section through the blade (AML sample no. 970003) and one 'V' section through the neck where it is bent at 90 degrees (AML sample no. 970004) (Fig 1).

Neck: 970004
Examination: unetched
Large quantity of well-rounded dual-phase inclusions and single-phase, glassy particles broadly aligned from centre to outer sides of the sections, with several narrow alignments. Some of the dual-phase is dendritic.

Etched
Both sections comprise mostly equiaxed ferrite but both also have regions of low-carbon (0.05%C maximum) iron comprising very fine pearlite and traces of grain-boundary carbide and some intragranular carbide (Plates 5 and 6). The blade section has a carburised region extending outwards along the centre (grain size ASTM 5); in the section from the neck it occurs at one side (grain size ASTM 7). The blade section also has some zones and bands of very large, mottled ferrite grains (grain size ASTM 2) — which achieved the highest hardness (204HV) and suggest the presence of phosphorus.

The composition of both specimens is very similar other than there being more mottled grains of ferrite in the blade. The characteristics of the grains and the pearlite are similar and do not indicate different thermal treatment. The pearlite is very fine suggesting rapid (air) cooling.

Hardness
Blade Ferrite (darkly etched band at side of section): 204 HV(0.2)
Ferrite + pearlite/carbide (centre of section): 116 HV(0.2)
Ferrite + carbide (side of section): 138 HV(0.2)
Neck Ferrite (side of section): 186 HV(0.2)
Ferrite + pearlite (side of section): 186 HV(0.2)

Interpretation
The spearhead was made from a mixture of ferritic iron and phosphoric iron, possibly welded together during smithing, but overall not very cleanly since there are abundant inclusion alignments. The lack of high carbon phases in the neck and blade means that it is not possible to determine any heating of the spearhead prior to bending. However, given the relatively pliable nature of the metal, the neck would have bent fairly easily without heating or undue pressure and without breaking.

General discussion

I) Technological assessment from X-radiographs

Technological features visible in the X-radiographs are often attributable to corrosion effects along interfaces, whether these are weld lines from incorporation of components such as steel edges, or from piling. Corrosion effects from piling (i.e. pile forging or folding and welding the metal during smithing to form the blade blank) can be visible due to stringers of non-metallic inclusions, or because of the proximity of metals of different composition. Volume and chemical variations can also contribute to the radiographic images.

In general, the blades from Boss Hall are better preserved than those from Buttermarket, in particular the spearheads. The latter may appear to retain greater proportions of metal when compared with the knives because of greater bulk of metal and smaller surface area. The differences in survival of ironwork between the sites is presumably a consequence of burial conditions.

X-radiography is not as effective as metallographic examination but nevertheless, some general observations can be made, although the interpretations from the radiographs and magnetic responses are limited in several ways. Firstly, certain types of features, for example butt-welds and complex welded-in components such as pattern-welding, are more readily detected by X-radiography, whereas other construction types may not be detected. Furthermore, heat treatments such as quench-hardening cannot be detected in this way. Secondly, the X-ray images are partly obscured by mineralised organic components, particularly where these are thick or complex. The blades are severely corroded, which has enhanced the survival of organic materials but diminished the information retrievable in the X-radiographs. If organic materials survive through mineralisation, this tends to occur soon after burial, before severe attack from micro-organisms and insects. This mineralisation is more pronounced in soil conditions which are aggressive to metals. Thirdly, the magnetic response will be lessened by thick corrosion layers including mineralised organic remains, and confused by the iron corrosion product magnetite (Fe_3O_4).

Seaxes

Of the three seaxes (from Buttermarket), X-radiographs of two showed no features but the third (3243/4 ▵6795) may have a complex construction of welded-in components, possibly pattern-welding.

Spearheads

There are eleven spearheads, of which ten showed evidence of piling or stringers and one of these (Boss Hall 95/2 ▵22) has evidence of a more complex structure along the centre of the blade. This was possibly a welded-in component. The magnetic responses are good in all of the spearheads from Boss Hall and suggest that metal survives extensively. Three was examined by metallography.

Knives (Table 5)
One knife (Buttermarket 4344/2 ▵7667) is pattern-welded (Plate 1). Another may have a complex welded-in structure, conceivably a pattern-welded component, and four others have possible complex structures but the radiographic evidence is inconclusive. 17 knives have possible weld lines along their blades. In nine cases the weld line is fairly well defined and positioned close to the cutting edge, or no more than half way up the blade, and these probably result from steel edges having been applied using butt-welds. In other examples the weld line is further from the blade edge which seems less likely therefore to be a simple steel edge, but may be a more complex construction type. Other knives show a series of parallel lines or bands, which may result from processes such as piling.

Some general conclusions can be made by comparing the features observable from the two sites (Table 5). The apparent differences in types of knife present were tested using the chi-squared test, with a significance level of 0.05. The results showed significant differences between the assemblages from the two sites, in particular due to the high proportion of complex and pattern-welded forms at Buttermarket and more frequent occurrence of piled blades at Boss Hall. However, there were similar numbers of simple butt-welded blades at both sites. Thus, at the later site of Buttermarket, the blades seem to demonstrate more advanced levels of smithing craftsmanship.

Table 5. Knives: summary of features visible in the radiographs

Feature	Boss Hall	Buttermarket	Total
Pattern-welded	0	1	1
Complex	1	4	5
Weld line	8	9	17
Probable piling/stringers	6	1	7
No features visible	5	8	13
No X-radiograph	2	0	2
Total	22	23	45

Radiographic assessments can fail to detect several types of blade construction, for example blades made entirely of steel, with steel cores, or with steel wrapped around a core of iron (cf. Tylecote and Gilmour 1986, fig. 1). The Ipswich assemblages could very possibly contain such types of construction since they occur in significant proportions at several other cemeteries of similar date. For example, at Lovedon Hill, Lincolnshire, where five knives from fifth to seventh century graves were analysed (McDonnell 1989), at Empingham II, Rutland, where 12 knives from sixth century graves were analysed (Wiemer 1996), and at Edix Hill (Barrington A), Cambridgeshire, where 17 knives from sixth to seventh century graves were analysed, including two pattern-welded knives (Gilmour and Salter 1999).

Simple or complex welds are visible in half of the blades from Ipswich. A similar radiographic study of 168 knives from fifth to seventh century graves at

Mucking, Essex revealed far fewer weld lines, present in only a quarter of the knife blades (Starley 1996). One explanation for this apparent high proportion of weld lines from Ipswich may be poorer quality smithing, namely failure to reduce the number and size of inclusion particles during the welding process — which later show up in X-radiographs as heavily corroded lines. However, uncertainties such as this can only be resolved by metallography where condition and other factors permit.

ii) Metallography

The three spearheads sampled (from Boss Hall) are made from ferritic iron with traces of carbon. Two (74/8 ∆78 and 87/2 ∆19) probably contain regions of phosphoric iron; there is evidence of piling but there has been incomplete homogenisation. There was no attempt to harden the edges of any of the blades, for example by inserting steel components, selectively carburising, heat treatments, or by cold working. One spearhead (87/2 ∆19) was examined at the bent neck as well as the blade to determine if there had been any preferential heating to assist bending. Reheating prior to bending seems unlikely, and should have been unnecessary since the metal is relatively soft.

Although the sampled group is small, they seem to be of poor quality compared with those from some other cemeteries. A metallographic study of nine spearheads from fifth to seventh century graves from the Anglian cemetery at West Heslerton, Yorkshire showed that blade edges there were often hardened (Moir 1990). This was accomplished by welding together metals of different compositions to exploit the greater hardness achievable with phosphoric iron or steel. Nevertheless, the use of steel and of heat treatments to harden the implements was rare (Moir 1990). A metallographic study of 20 spearheads from Edix Hill (Barrington A), found several different types of constructions including two unusual forms of pattern-welding and three blades containing steel (Gilmour and Salter 1999). Overall, however, the quality of the spearheads was lower than the knives examined from the same cemetery (Gilmour and Salter 1999). A wide range of construction types for spearheads is also suggested by a radiographic study of 65 spearheads from Mucking, Essex, including eight possible pattern-welded forms (Starley 1996).

There could be several explanations why the Boss Hall spearheads seem to be technically poor. They may have been devised specially for non-functional, symbolic purposes, although this is contrary to the generally accepted interpretation that most Saxon graves contain personal possessions rather than artefacts which were specially manufactured for funerary purposes. Alternatively, their methods of use in combat may not have required high quality metal throughout the blades, for example the blades could have been hardened only at their extreme tips. Certainly the sophisticated methods of manufacture used for knife blades, for example at Empingham (Wiemer 1996) and at Barrington (Gilmour and Salter 1999), do not seem to have been exploited for spearheads of the same period.

Conclusions

In general, where iron mineralisation has been sufficiently extensive to preserve the organic components, metal survival can be expected to be poor. Even though this is the case at Boss Hall and Buttermarket it was possible to make some observations on possible methods of blade construction from the X-radiographs. At both sites a large proportion of the blades had been butt-welded, presumably to apply a steel edge to a low carbon blade back. Differences between the two assemblages included higher numbers of blades with pattern-welding or other complex structures at Buttermarket and more evidence of piling of the metal at Boss Hall. Metal survived more extensively in the spearheads from Boss Hall and three were sampled for metallographic examination. All were made of low quality iron and no attempt had been made to harden the blade edges.

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