1600

Ancient Monuments Laboratory
Report 70/98

METALLOGRAPHIC EXAMINATION OF SEVEN MEDIEVAL KNIVES FROM EYNSHAM ABBEY, OXFORDSHIRE

V Fell
D Starley

Ancient Monuments Laboratory Report 70/98

METALLOGRAPHIC EXAMINATION OF SEVEN MEDIEVAL KNIVES FROM EYNSHAM ABBEY, OXFORDSHIRE

V Fell
D Starley

Summary

Seven knives were examined by metallography to investigate quality and methods of manufacture. The knives are from unrelated contexts and span late Saxon to post-medieval periods. Most of the knives are composite structures and include good quality steels which were heat treated. Two, and possibly a third, have pattern-welded backs.

Authors' addresses :-

Ms V Fell
INSTITUTE OF ARCHAEOLOGY (OXFORD)
University of Oxford
36 Beaumont Street
Oxford
OXON
OX1 2PG

Dr D Starley
ENGLISH HERITAGE
23 Savile Row
London
W1X 1AB

Metallographic examination of seven medieval knives from Eynsham Abbey, Oxfordshire

Vanessa Fell and David Starley

Introduction

The knives to be analysed were selected by the finds specialist (P.J. Ottaway) to cover the main periods of occupation, spanning late Saxon to post medieval periods (Table 1). This report presents the analytical results using optical microscopy and hardness testing to examine quality and methods of manufacture. Elemental analysis has not been undertaken.

The knives are divided here into blade structure types (Fig. 1) described originally by Tylecote and Gilmour (1986, 2-3, fig. 1) and used subsequently to categorise the knives from Coppergate, York (McDonnell and Ottaway 1992, 484, fig. 178). Technical aspects are defined in Samuels (1980).

Methods of examination

Two overlapping half-sections were removed from each blade where condition permitted (Fig. 2). One blade (△158) could be sampled only through the back; another (△1507) was sampled vertically through the extant blade where broken. Sample positions were selected according to condition and to features visible in 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 then 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. Microhardness readings are averaged Vickers Pyramidal values obtained using loads of 0.2kg or 0.5kg applied for 30s.

Table 1. Knives sampled

SF	Context	AML no.	Phase	Provisional date
158	440	980001	2X	late Saxon
209	599	980002	3C	C13
404	659	980003	4A	C16
434	604	980004	2X	late Saxon
816	817	980005	3B	C12
1242	1565	980006	4A	C16
1507	3522	980007	3E	C15-C16

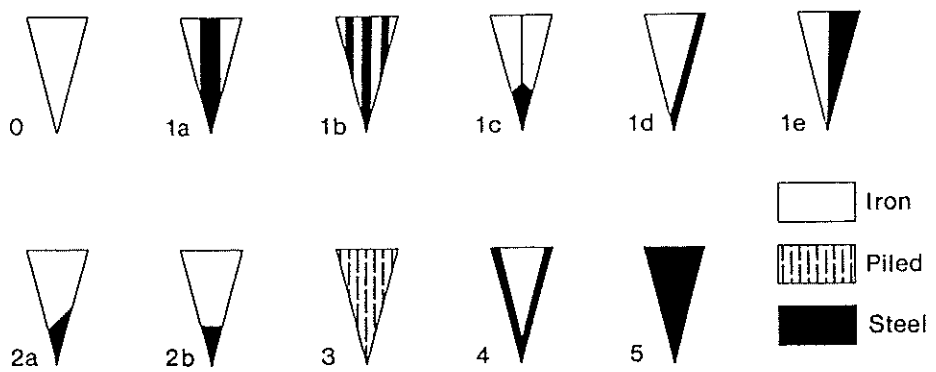
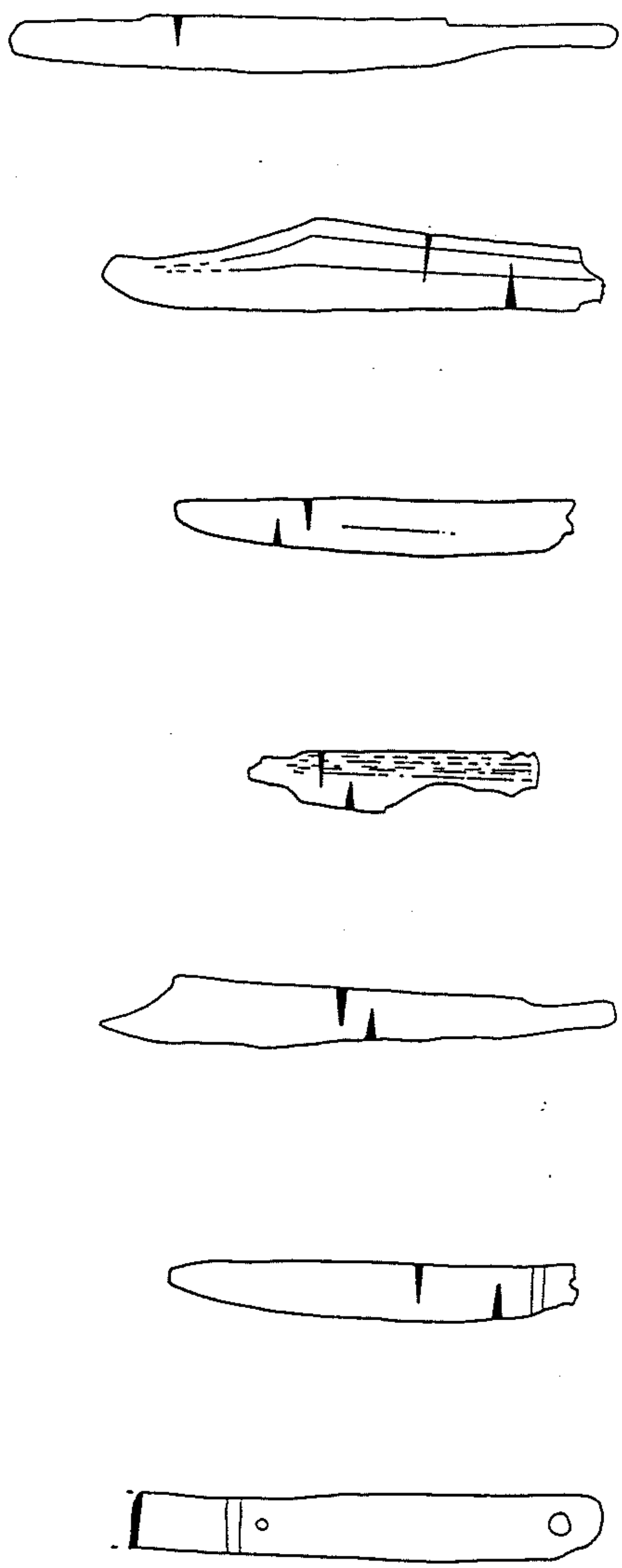


Figure 1. Schematic cross-sections of blade structure types (after McDonnell and Ottaway 1992, fig. 178)

Results

The results are summarised in Table 2 and described in detail thereafter (p 6–11) followed by a brief discussion (p12). Figure 3 illustrates the main structural regions determined in the blades (in the areas examined).



△158 (980001)

△209 (980002)

△404 (980003)

△434 (980004)

△816 (980005)

△1242 (980006)

△1507 (980007)

Figure 2. The knives sampled showing location of specimens. Scale 1:2

Table 2. Summary of metallographic results

SF no.	AML no.	Microstructure		Carbon	Hardness HV	Blade structure type
158	980001	Back:	F	0	140 HV(0.2)	1c
			M	medium	684 HV(0.5)	
209	980002	Edge:	M+P	high	571 HV(0.5)	2b
		Centre:	F, M+P	low	-	
		Back:	F	0	92 HV(0.2)	
			M+P	?medium	312 HV(0.2)	
404	980003	Edge:	M	high	543 HV(0.5)	4 ?
434	980004	Edge:	M	high	733 HV(0.5)	2b
		Back:	F/M	0/low	-	
816	980005	Edge:	M+P	?medium	218 HV(0.2)	1c
		Back:	F	0	107 HV(0.2)	
			Phos	0	184 HV(0.2)	
			M+P	low/medium	211 HV(0.2)	
1242	980006	Edge:	F+M	low	222 HV(0.2)	3
			F	0	133 HV(0.2)	
		Back:	M	low/med	346 HV(0.5)	
			B	low	165 HV(0.2)	
1507	980007	Centre:	TM	low/med	197 HV(0.2)	–
			TM	low/med	329 HV(0.2)	
			TM	low/med	311 HV(0.2)	

B, bainite; F, ferrite; M, martensite; TM, tempered martensite; P, irresolvable pearlite; Phos, phosphoric iron

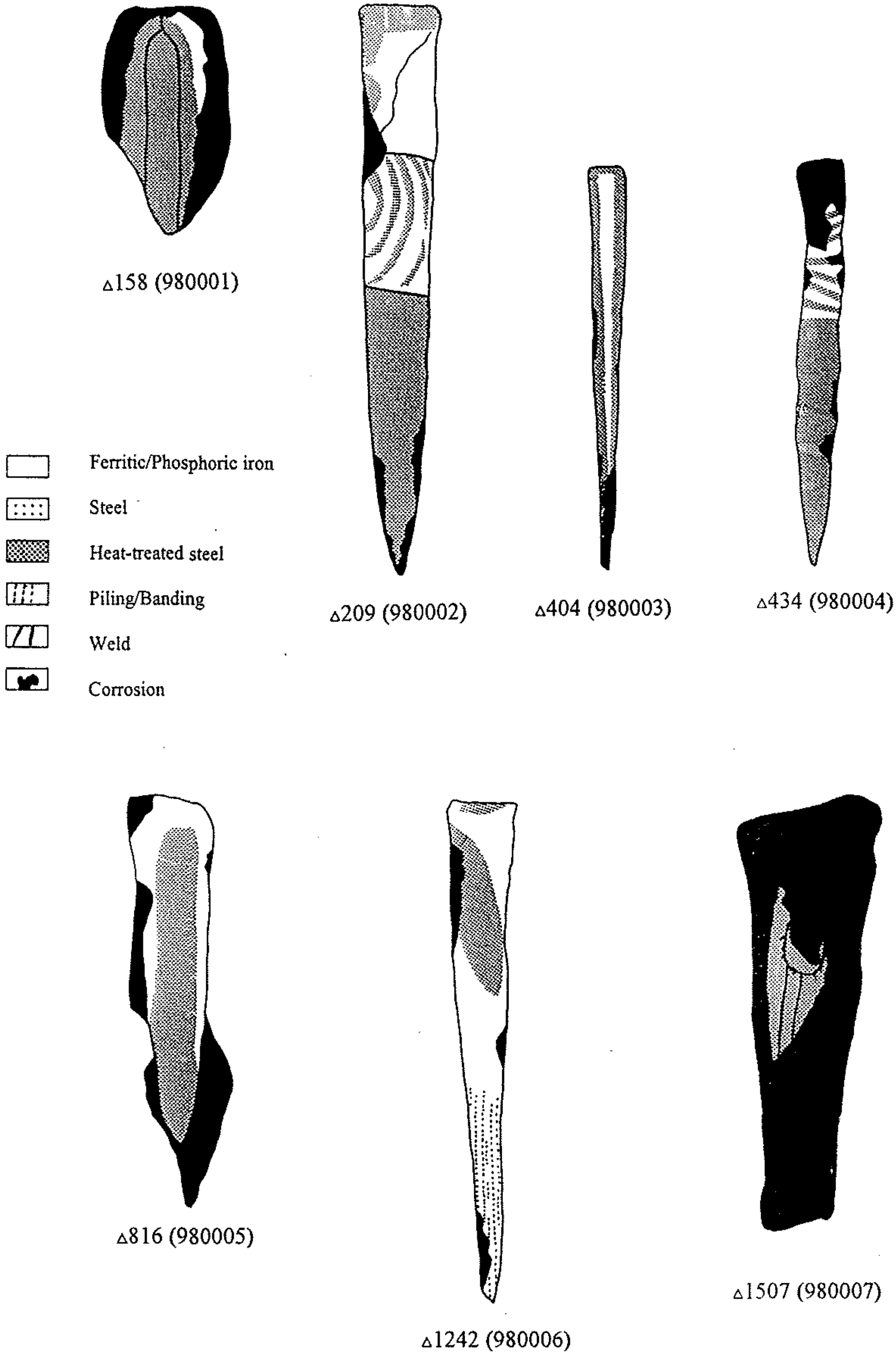


Figure 3. Schematic cross-sections of the knives showing main structural regions. Scale 5:1

980001 Knife △158

Context 440; Phase 2X; X-ray (Ox) 418
Figures 2 and 3; Plates 1 and 2
Blade structure type 1c

Sample
Single half section, through the blade back. The x-radiograph does not assist interpretation of the metallurgy. The blade's cutting edge is too corroded to sample.

Examination: unetched
Corroded at the sides. The bulk of the non-metallic inclusions are single-phase/glassy and are aligned vertically from blade back to the edge. There are two types. Well-broken stringers are aligned within the high-carbon zone. Other inclusions are larger and more angular; some are aligned particularly where they coincide with the light-etching lines.

Etched
There is a central medium- or high-carbon zone (hardness 684 HV) comprising martensite (?tempered) and bainite plus some irresolvable pearlite. A light-etching ('white') line forms an elongated arc around this carburized zone (Plates 1 and 2). There is a sharp gradient in carbon composition at one side of the specimen to a zone comprising ferrite (hardness 140 HV), whereas the other side has a less pronounced gradient. Some of these ferrite grains look strained internally, as if they were only partly annealed during the final heating.

Hardness
Ferrite: 140 HV(0.2)
Martensite: 684 HV(0.5)

Interpretation
A high-carbon steel core was inserted into a ferrite back (blade type 1c). Carbon has diffused across the weld lines producing carbon gradients to each side of the core. The blade was incompletely annealed, then quenched and possibly tempered.

980002 Knife △209

Context 599; Phase 3C; X-ray (Ox) 419
Figures 2 and 3. Plates 3 and 4
Blade structure type: 2b

Sample
The x-radiograph suggests a pattern-welded band (c. 4–8 mm width) along the length of the blade, c. 5mm down from the back. Half sections were taken from the cutting

edge and the blade back.

Examination: unetched
Metal survives well. Near the extreme cutting edge there is a small amount of single-phase non-metallic inclusions. At the back there are more inclusions: (a) mainly dual-phase and distributed irregularly near the blade back, (b) denser concentrations of broad curves of small aligned inclusions at the centre. The three weld lines across the sections comprise small, glassy inclusions.

Etched
The structure divides into three main broad zones with clear weld lines between.

The cutting edge (c. half the depth of the blade) is small grained, uniform, high-carbon composition comprising mainly martensite with irresolvable pearlite and slight traces of grain-boundary carbide. Hardness at the blade edge, 571 HV.

The central zone comprises numerous curved bands (Plate 3) of variable carbon content (all low-carbon). The grain size is small. The carbon tends to be at grain boundaries and is spiky or feathery — probably a mixture of martensite and irresolvable pearlite (cf Samuels 1980, 68, figs 13-14).

The blade back comprises regions of large-grained ferrite (92 HV), low-carbon regions where the martensite is feathery, and higher-carbon regions at the back (312 HV) and towards the extant side of the section. There are smooth carbon gradients between these regions, and a weld extending diagonally across this area.

The transformation products etch rapidly and darkly and look slightly tempered, although this is uncertain.

Hardness
Cutting edge (martensite + irresolvable pearlite): 571 HV(0.5)
Back (martensite + irresolvable pearlite): 312 HV(0.2)
Back (ferrite): 92 HV(0.2)

Interpretation
A high-carbon steel edge was applied to a pattern-welded core which probably extends along the length of the blade (type 2b). The blade back is variable in carbon composition and is poorly homogenised. The blade was quenched mildly ('slack-quenched'), possibly from the partly austenitised condition (suggested by the accicular appearance of martensite in places, as well as the grain-boundary carbide in the high-carbon zone). It was possibly tempered. The blade edge is deep and uniform in structure where sampled. A high-quality blade.

980003 Knife △404

Context 659; Phase 4A; X-ray (Ox) 420
Figures 2 and 3. Plate 5
Blade structure type: 4 (?)

Samples
The x-radiograph hints at a weld line half-way down the blade, but only for half the length of the blade, at the tang end. Half sections were taken from the cutting edge and the back towards the blade tip.

Examination: unetched
Metal survives well except at the extremity of the cutting edge. The non-metallic inclusions are mostly multi-phase, aligned from the blade back to the tip in several lines, but mainly at the centre, and extending from edge to back.

Etched
There is a carbon gradient from high-carbon at the sides of the sections to low at the centre (Plate 5). Light-etching lines give a banded appearance, coinciding with the non-metallic inclusions, and aligned from the back to the cutting edge. The constituents comprise predominantly martensite (hardness 543 HV); there is also some bainite and irresolvable pearlite (plus ferrite at lowest carbon area). The martensite is spiky at the low-carbon area. The constituents look tempered. Uniform small grains.

Hardness
Edge (martensite): 543 HV(0.5); 548 HV(0.2)

Interpretation
The alignments of inclusions and structure suggest that the metal has been welded several times and that carbon has diffused. The structure may be explained in two ways: by steel having been wrapped around an iron core (blade type 4) or by piling of low- and high-carbon metals (blade type 1b). The former seems more likely. The blade was finally quenched and probably tempered.

980004 Knife △434

Context 604; Phase 2X; X-ray (Ox) 421
Figures 2 and 3. Plates 6 and 7.
Blade structure type: 2b

Samples
The x-radiograph suggests two clearly distinguishable zones, a pattern-welded back and a cutting edge of more uniform structure. Half sections were taken from the cutting edge and blade back.

Examination: unetched
Very corroded in the back. The edge has a small amount of well-broken, single-phase (glassy) non-metallic inclusions aligned vertically from blade back to the edge. The back has alignments of abundant rounded inclusions (single-phase and some multi-phase) running diagonally across the specimen.

Etched
The edge is a high-carbon, small grained, very uniform structure comprising predominantly martensite (Plate 7), with a small amount of ferrite associated with bainite towards the centre of the blade, and some free carbide towards the blade's extreme edge. Etching was very rapid.

The high-carbon edge joins a region of diagonal bands (ten or more bands) which form the blade back, and continue into the corrosion layers (Plate 6). The bands comprise alternate low-carbon zones of martensite and almost carbon-free zones of ferrite with some spiky martensite or other transformation product. The latter constituents are outlined with regions which can not be focussed. (These bands are too corroded to enable hardness testing.)

Hardness
Edge (martensite): 733 HV(0.5)

Interpretation
A high-carbon edge has been applied to a pattern-welded back (blade type 2b). It was severely quenched and possibly lightly tempered. This is a high-quality blade.

980005 Knife △816

Context 817; Phase 3B; X-ray (Ox) 423
Figures 2 and 3. Plates 8 and 9.
Blade structure type: 1c

Samples
Half sections were taken through blade back and the cutting edge. The x-radiograph does not assist interpretation of the method of manufacture.

Examination: unetched
Corroded at the sides and at the extreme cutting edge. Non-metallic inclusions are elongated, glassy and dual-phase aligned from the back to the edge. Some are aligned in narrow bands, especially to the sides of the sections, but most are not grouped.

Etched
A core comprising low/medium-carbon steel is surrounded by very low carbon iron (<0.1% C) which forms the back and extends down the sides of the blade (Plate 8). There are several vertical alignments of light-etching lines (and inclusions), and a more pronounced weld line near the blade back.

In the core, the carbon constituents are mainly martensite and irresolvable pearlite (some feathery) with some bainite (Plate 9). Very small grains. The extant blade edge is higher in carbon composition and is more uniform in structure than the rest of the blade. The constituents appear heavily (over) tempered (hardness 218 HV near the extant edge; 211 HV near the back).

The back comprises equiaxed ferrite and some carbon. Some of the ferrite is mottled suggesting the presence of phosphorus; hardness readings in these grains gave 184 HV whereas elsewhere in the ferrite grains hardness values were only 107 HV. There is some banding in the structure and some carbon migration. The carbon constituents are similar to those in the core; some spikiness of the constituents suggest incomplete austenitization.

Hardness
Back (ferrite): 107 HV(0.2)
Back: (phosphoric iron): 184 HV(0.2)
Back (martensite + irresolvable pearlite): 211 HV(0.2)
Edge (martensite + irresolvable pearlite): 218 HV(0.2)

Interpretation
An iron back has been wrapped around a steel core (blade type 1c). The whole was quenched and then over tempered, resulting in a rather soft and not very efficient blade. There is always a possibility that the over-tempering occurred later in the history of the blade.

980006 Knife △1242

Context 1565; Phase 4A; X-ray (Ox) 424
Figures 2 and 3. Plates 10 and 11.
Blade structure type: 3

Sample
Radiograph suggests possible weld lines (or slag lines) along the blade centre. Half sections were taken from the blade back and the cutting edge.

Examination: unetched
Metal survives well. There is a small amount of inclusions, mostly multi-phased and aligned (vertically from blade back to edge) except near the back where there are more abundant, well-rounded, dual-phase inclusions forming at least four diagonal broad bands.

Etched
The cutting edge has a very low-carbon composition, comprising ferrite with transition products (spiky martensite/bainite/irresolvable pearlite). The structure has a banded appearance (Plate 10) due to mottled ferrite of variable grain size, and that martensite has segregated at grain-boundaries. Nearer the blade centre there is less martensite and more ferrite which is larger grained.

The back has a carburised zone (low- or medium-carbon) which extends across the section, comprising mainly martensite at the higher carbon area (Plate 11), mainly bainite where there is less carbon. At the extreme back the carbon content increases again slightly. Away from the carburised areas the main constituents are ferrite with traces of bainite. Some of the ferrite is mottled. There is some banding within the bainite zone diagonally across the blade and associated with the inclusions.

Hardness
Edge (ferrite + spiky martensite): 222 HV(0.2)
Centre (ferrite): 133 HV(0.2)
Back (martensite): 346 HV(0.5)
Back (bainite): 165 HV(0.2)

Interpretation
The centre and back of the blade are reasonable quality steel and there seems to have been some attempt to pattern-weld the back. The cutting edge, however, is very poor quality low-carbon iron, possibly piled from strips of variable composition (blade type 3), resulting in an unsatisfactory blade. The blade was quenched but not tempered.

980007 Knife ▵1507

Context 3522; Phase 3E; X-ray (Ox) 426
Figures 2 and 3. Plate 12.
Blade structure type: ?

Sample
A single section was taken at the extant end of the blade, c. 20mm from ferrule, through the depth of the blade.

Examination: unetched
Very corroded (less than 20% survives as metal). Specimen is very clean; some single-phase, elongated, glassy inclusions are aligned at the edge of zone C and orientated longitudinally within zone B, plus some broader multi-phase inclusions.

Etched
Three zones of similar constituents, differentiated by inclusion alignments, light-etching lines and degree of etching. Very small grained, especially Zone A. Carbon composition and grain size appears similar in each zone. Carbon has spheroidised to grain boundaries and along intra-granular planes; appearance is reminiscent of martensite structure (Plate 12).

Hardness
Zone A: 197 HV (0.2)
Zone B: 329 HV (0.2)
Zone C: 311 HV (0.2)

Interpretation
Cannot be reliably interpreted from this specimen, but was possibly very clean and well-homogenised steel of medium- or high-carbon composition, welded from two or more components. Was probably quenched and subsequently heavily (over) tempered.

Discussion

The small number of knives sampled from Eynsham Abbey provides only a limited data set to study the production of knives over a broad span of time. However, they do serve to show the considerable variety of methods for manufacturing blades, as well as demonstrating access to different alloy types. Although iron/phosphorus alloy seems likely in one blade, the others generally comprise iron and steel (ie an alloy of iron and carbon), fire-welded together in such a way as to provide a good steel cutting edge on a low-carbon iron back. Such a combination has two advantages. Firstly, because steel is more difficult to manufacture than iron, or more costly to buy, it is used more economically. Secondly, when the blade is quenched, the steel will be further hardened and able to retain a keen edge, whilst the iron in the back will be largely unchanged and not become embrittled, giving maximum toughness.

It may be significant that the two most effective blades (∆158 and ∆434) are the earliest knives examined (Phase 2X, late Saxon). These are both economical in their use of steel and have the hardest edges of all the knives examined. The blade back of ∆434 was also pattern-welded, being built up of alternating layers of steel and iron, welded together. In the finished blade, when ground, polished and etched, this would have had a pleasing decorative effect and the blade is certainly the product of a highly skilled craftsman. Blade ∆209 demonstrates that high quality pattern-welded knives continued to be used into at least the thirteenth century. The quality of blade ∆816 is harder to assess. Its effectiveness has been considerably reduced by over tempering. Although this may be due to a lack of good judgement on the part of the blacksmith, in reheating the blade to remove stresses, the damage could equally have been done at a later date, for instance by accidentally dropping the blade into a fierce fire. The fifteenth/sixteenth century blade (∆1507) was unfortunately too corroded to provide much useful information. Beyond this date, the post-medieval is represented by only two blades, ∆404 and ∆1242, which are relatively poor quality implements, showing indifferent craftsmanship compared with the earlier examples.

For the earlier knives, the high proportion of steel-edged blades is matched by mid-Saxon blades from Hamwic, Southampton (McDonnell 1987a & b) and ninth/tenth century blades from Coppergate, York (McDonnell and Ottaway 1992). There are relatively few metallographic studies of later medieval knives. However, some parallels come from Winchester where a high proportion of twelfth to fourteenth century blades are steel edged (although the hardness values for the edges are disappointing), with greater diversity in the sixteenth century (Tylecote 1990). Similarly, from London, twelfth to early/mid-fifteenth century knives have been shown to frequently have heat-treated steeled edges (Wilthew 1987).

Bibliography

McDonnell, J G (1987a) 'Metallurgical Analyses of Six Iron Knives from Hamwih, Southampton', Ancient Monuments Laboratory Report 93/87.

McDonnell, J G (1987b) 'Analyses of Eight Iron Knives and Four Other Tools from Hamwih, Southampton' Ancient Monuments Laboratory Report 137/87.

McDonnell, J G and Ottaway, Patrick (1992) 'The smithing process' in Ottaway, P, *Anglo-Scandinavian Ironwork from 16–22 Coppergate*. The Archaeology of York 17/6. London: CBA.

Samuels, L E (1980) *Optical Microscopy of Carbon Steels.* Ohio: American Society for Metals.

Tylecote, R F (1990) 'Scientific examination and analysis of iron objects', in M Biddle, *Object and Economy in Medieval Winchester*, Winchester Studies 7ii (Pt i), 140-159.

Tylecote, R F and Gilmour, B J J (1986) *The Metallography of Early Edge Tools and Weapons.* Oxford: BAR Brit Ser 155.

Wilthew, P (1987) 'Metallographic examination of medieval knives and shears' in J Cowgill, M de Neergaard and N Griffiths, *Knives and Scabbards: Medieval Finds from Excavations in London,1.* London, HMSO, 62-74.

Plate 1. Knife △158 (980001), with blade back orientated at the top. Weld lines (white) separate the higher-carbon core comprising martensite (centre, dark) from the lower-carbon back (left and right). X50. Nital etch

Plate 2. Knife △158 (980001). Detail: martensite (dark), with weld lines (white) and dual-phase inclusions at centre top weld. X100. Nital etch

Plate 3. Knife △209 (980002). Pattern-welded zone at blade centre, the bands formed of variable carbon content, the darker etching areas containing more carbon. X50. Nital etch

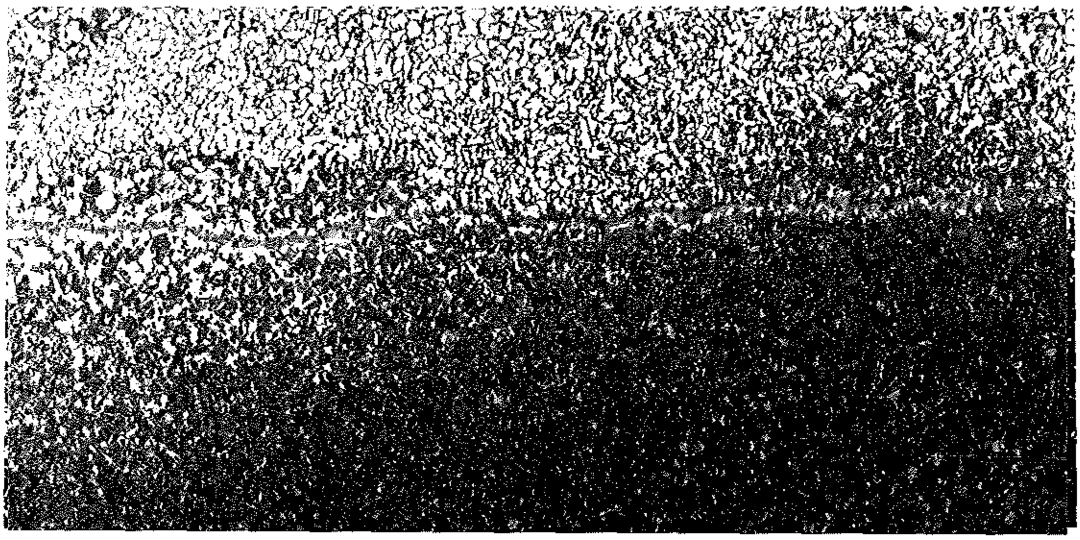


Plate 4. Knife △209 (980002). Detail of weld (visible in Plate 3, lower) between high-carbon cutting edge (lower) and the pattern-welded core. X100. Nital etch

Plate 5. Knife ▵404 (980003). Centre of blade, with cutting edge to the left, showing banded structure comprising mainly martensite (darkly etching) and bainite (lighter etching). X100. Nital etch

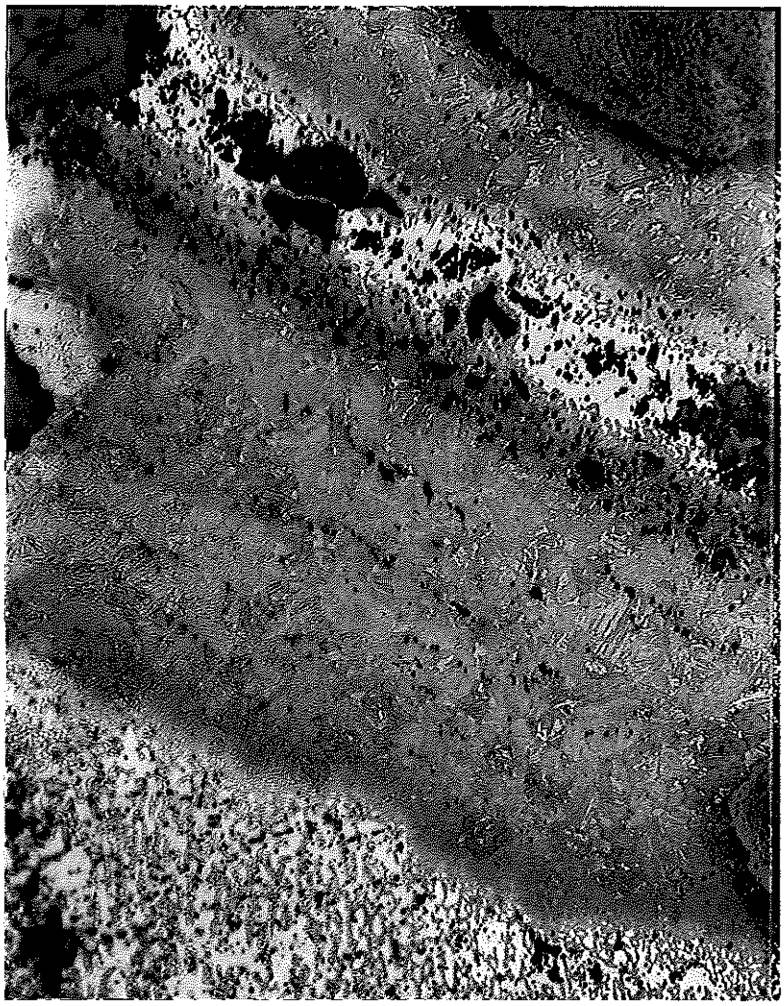


Plate 6. Knife ▵434 (980004). Pattern-welded back showing diagonal bands comprising mainly martensite in the broad mid-grey band at centre, and bands of mainly ferrite with non-metallic inclusions to each side. X100. Nital etch

Plate 7. Knife ▵434 (980004). Martensite at the cutting edge. X200. Nital etch

Plate 8. Knife ▵816 (980005). Blade back (at top). Ferrite (light etching) was wrapped around a core (darker etching) of higher-carbon content comprising martensite and pearlite. X50. Nital etch

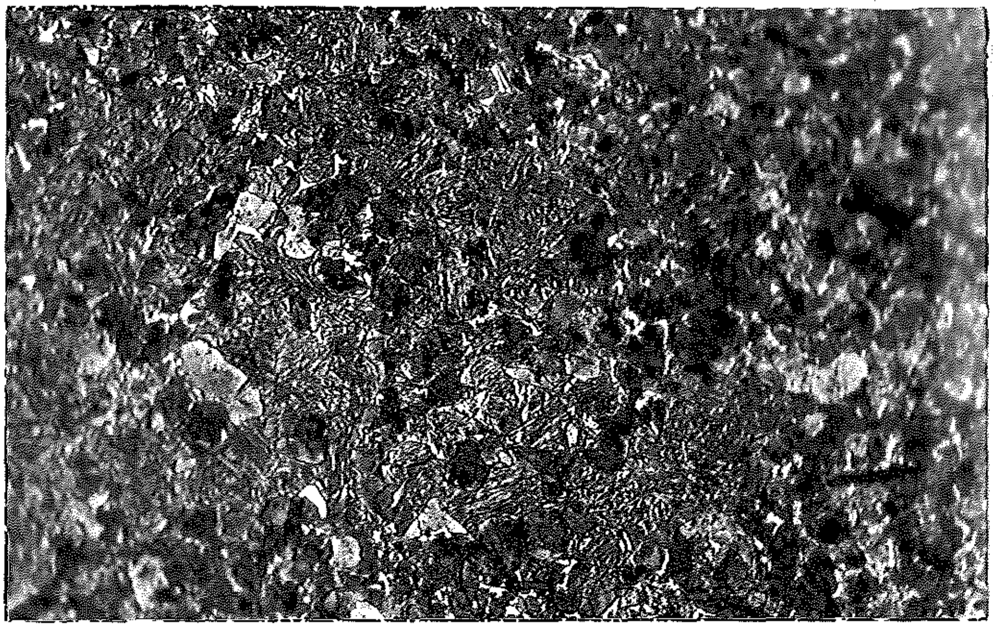


Plate 9. Knife △816 (980005). Detail of martensite and irresolvable pearlite. X400. Nital etch

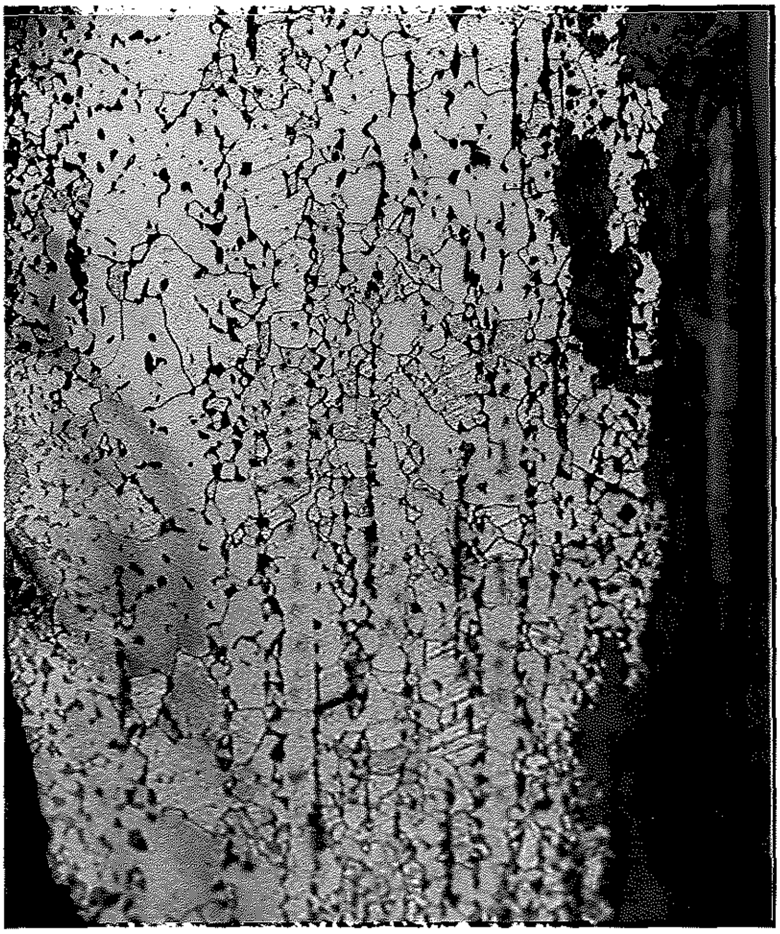


Plate 10. Knife △1242 (980006). Banded structure towards the cutting edge (orientated at the base) comprising mainly ferrite. X100. Nital etch

Plate 11. Knife △1242 (980006). Detail of martensite at the blade back. X100. Nital etch

Plate 12. Knife △1507 (980007). Microstructure near a weld line (?over tempered martensite). X200. Nital etch