Metallographic examination of seven Iron Age ferrous axeheads from England

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Abstract

Two socketed and five shaft-hole ferrous axeheads were examined by metallography and electron probe microanalyser. Specimens from the cutting edges revealed low carbon compositions although two and possibly a third showed evidence of secondary (surface) carburization. All had been cooled naturally during their final heating cycles.

Introduction

Ferrous axeheads from the pre-Roman Iron Age in Britain are divided according to the means of hafting into socketed and shaft-hole types. A study by Manning and Saunders (1972) describes the examples known at the time (21 socketed and 7 shaft-hole) and discusses their provenances and dating. There are a few more recent discoveries, five of which are included here.

This article synthesises the results of metallographic examination (VF) and microanalysis (CJS) of specimens from the cutting edges of two socketed, looped axeheads and five shaft-hole axeheads (Table 1, Fig 1). Three were sampled by other workers and were re-examined for the present study. Two of these axeheads (Nos 6 and 7) were originally investigated principally for element composition of the metal (Ehrenreich 1985, HNY33a and B5a). The other (No 4) was originally sampled for analysis of corrosion products (Miller *et al* in Field forthcoming) and the metallographic results will be more fully published in the archaeological site report together with two other axeheads (Nos 3 and 5) sampled from the same site (Fell in Field forthcoming).

The majority of the Iron Age axeheads from Britain (including three reported on here) are casual finds and their dating is unclear. Of great interest therefore is a recently obtained radiocarbon date of a sample of the wooden hafting from the socket of axehead No 2, dated to 2480±50 BP (OxA-6216), which calibrates at 2 sigma to the 8th-5th centuries BC (Hedges *et al* 1997, 250). Socketed axeheads, which are either looped or unlooped, are generally thought to be earlier forms mimicking bronze examples of the Late Bronze Age. It has been suggested that the shaft-hole axe was a late introduction, probably as a consequence of Roman contact (Manning and Saunders 1972, 282), although Irish examples have been ascribed to the earlier Iron Age (Scott 1990, 49). Until further examples of both types are recovered from more clearly datable contexts, chronological sequencing remains uncertain.

Methods

The axeheads were sampled through their cutting edges at positions selected with reference to X-radiographs, and incorporate corrosion layers where present (Nos 1–5). The samples were mounted in longitudinal orientation to provide cross-sections of the cutting edge, ground and polished to $^1/_4\mu$m fineness according to standard metallographic procedure and etched with 1% nital. Microhardness measurements are Vickers Pyramidal values (averaged) obtained using a 0.2kg load. Carbon content was estimated optically from the proportion of pearlite present (carbides). Grain size was estimated with an eyepiece graticule at x100 magnification.

Minor and trace elements were analysed using the Cameca SEMPROBE wavelength dispersive analytical scanning electron microscope (Research Laboratory for Archaeology and History of Art, Oxford). The specimens were digitally mapped for phosphorus to determine the positions to be fully analysed. Once selected, small areas free of non-metallic inclusions, typically 30 x 40μm or less across, were analysed for the minor and trace elements (Si, P, S, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, As) in the metal, using 100nA current and 100s counting times for all elements. At least eight different positions per specimen were analysed.

Only elements P, S, Co, Ni, Cu and As were detected consistently at levels above the detection limits of the microprobe. Thus, the data set is directly comparable with earlier electron microprobe studies of British artifacts (Salter and Hedges 1979; Ehrenreich 1985). The reason for the use of the extended element set is two-fold. Even though most of the additional elements do not normally occur at levels above their detection limits, elements such as Si and Mn do give an indication of invisible sub-surface inclusions that might perturb the analytical results. Iron from later periods has been found to contain some of these elements at levels above the detection limits, therefore all twelve metallic minor and trace elements are now analysed as routine, although only six are reported in Table 3.

Results

The results from metallography are summarised in Table 2 and trace and minor element compositions are summarised in Table 3. The principal features are:

Carbon compositions away from the edges of each specimen were low and relatively uniformly distributed, ranging from almost carbon-free (No 2) to 0.4% carbon (No 5). Microstructures comprised pearlite, sometimes with grain-boundary cementite (including very slight traces in No 2).

At the edges of the specimens from Nos 3 and 4, corresponding to the surfaces of the axeheads, there were gradients in carbon concentration from high at the metal/corrosion interfaces to low in the interiors (Figs 2–4). These gradients were discontinuous (see Fig 2), presumably through corrosion, but where present they persisted within the adjacent surface corrosion layers as remanent carbides. Gradients such as these are characteristic of secondary (surface) carburization. Axehead No 5 also had high levels of remanent carbides surviving intermittently within its surface corrosion layers (Figs 5 and 6).

Hardness values in the interiors of the specimens ranged from 148 to 199 HV (0.2), whereas those with enhanced carbon levels at the edges had hardness values measurable up to 258 HV (0.2).

Specimens revealed lines of well-broken stringers of non-metallic inclusions (multi-phased and glassy) orientated in the direction of the long axes of the axeheads. Corrosion had penetrated larger stringers in Nos 1, 3 and 5.

Four axeheads revealed light-etching lines orientated parallel and sometimes coincidental with the non-metallic inclusions (Nos 3, 5, 6 and 7). Carbon was not normally depleted within these lines.

Analysis of minor and trace elements (Table 3) showed

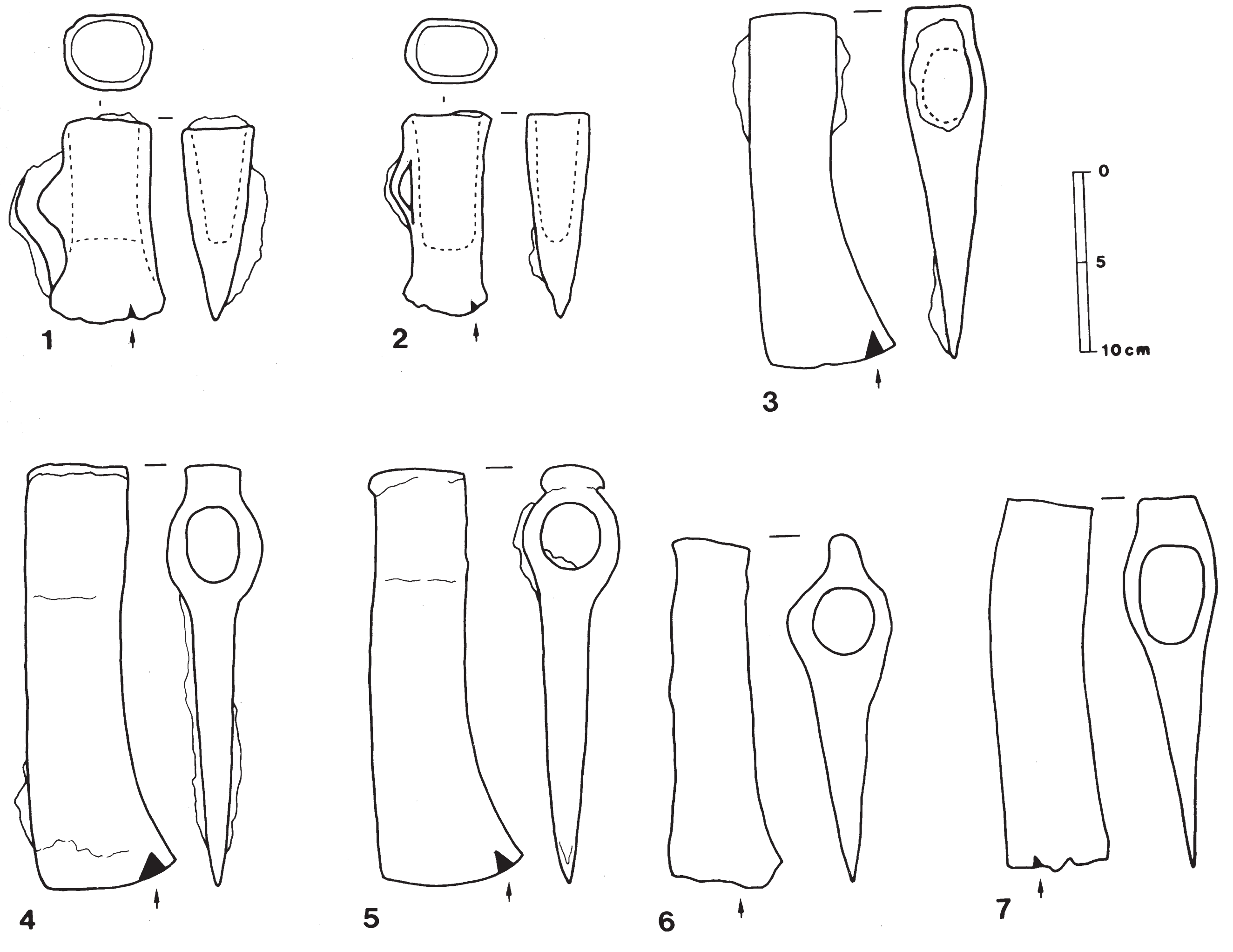

Fig 1: Axeheads 1 to 7 showing positions of metallographic samples.

Table 1: Iron Age axeheads examined by metallography

No	Identity	Provenance
Socketed, looped		
1	Fengate, Cambridgeshire	From mixed stratigraphy at Fengate Power Station post alignment, Area 1 (Coombe 1992, 516, fig 7:4).
2	Buscot	Found in dredgings by the edge of the river Thames at Biscot (Barclay *et al* 1995). Handle dates to 8th-5th centuries BC (Hedges *et al* 1997).
Shaft-hole		
3	Fiskerton, Lincolnshire (SF 331)	The three axeheads were excavated in 1981 near a 5th/4th century BC timber causeway together with metalworking tools and other woodworking tools (Field 1986; Field forthcoming). The group includes a float whose handle dates stylistically to *c*4th/3rd century BC (Stead 1985, 17-18).
4	Fiskerton, Lincolnshire (SF 413)	
5	Fiskerton, Lincolnshire (SF 383)	
6	Hunsbury, Northamptonshire (Northampton Museum No D318/1956-7)	Salvaged during 19th century quarrying for clay ironstone (Fell 1936, 65). The hillfort was occupied from 5th/4th to 1st century BC (Knight 1984).
7	Bigbury, Kent (Manchester Museum No 35812)	Discovered during gravel quarrying in 1895 and possibly associated with other ironwork (Boyd Dawkins 1902, 214, fig 2:c; Thompson 1983, fig 14:15, pl. xxiv:a). The hillfort was occupied from 5th/3rd to mid or late 1st century BC (Thompson 1983).

slightly raised levels of phosphorus in axeheads 1, 2, 3 and 7, although none was particularly high. Arsenic was also slightly raised in Nos 2, 3 and 5. The phosphorus distribution maps (*eg* Fig 7) showed concentration bands which were orientated longitudinally and parallel to the cutting edge; these features were more pronounced or were more visible in the distribution maps than in the etched specimens under optical microscopy.

All of the axeheads had been cooled naturally (*ie* air-cooled) from their final heating cycles.

Table 2: Summary of metallographic results.

No	Carbon (wt%)	Structural components	Hardness HV $_{0.2}$	Grain size ASTM
1	0.2	ferrite + pearlite	157-161	5-6
2	0.0	ferrite	148	3-4
3	< 0.1 (0.6)*	ferrite + pearlite	158 (258)*	5
4	< 0.1-0.2 (0.8)*	ferrite + pearlite	137 (235)*	6
5	0.2-0.4	ferrite + pearlite	156-173	5-7
6	0.0-0.1	ferrite + pearlite	120-125	4-6
7	0.1	ferrite + pearlite	199	7

( )* = measured at specimen edge (ie extant metal surface)

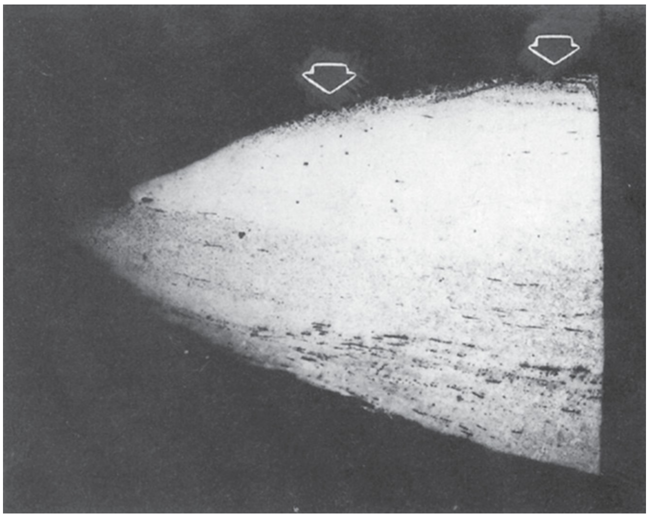

Fig 2: Axehead 3, whole specimen with cutting edge of axe at left, comprising low-carbon iron with non-metallic inclusions plus traces of carburization at the surface (arrowed). Nital etch (x 8).

Discussion

Carbon compositions

The overall carbon contents of the axeheads are not high and lie well within the normal range for Iron Age artifacts (Ehrenreich 1985; Fell 1990). Secondary carburization, visible in the specimens from axeheads Nos 3 and 4 and possibly also No 5 may be deliberate attempts to increase the carbon content and hardness at the cutting edges. However, there is always a chance that these enhancements arose through accidental carburization on a hearth, for example during manufacture. The carbon gradients are

Table 3: Electron microprobe analysis of minor and trace elements in the axeheads (weight %).

No		P	S	Co	Ni	Cu	As
1	mean	0.328	0.013	0.005	0.025	0.013	0.013
	std dev	0.098	0.002	0.005	0.003	0.011	0.011
	min	0.199	0.010	0.000	0.019	0.000	0.000
	max	0.496	0.017	0.014	0.029	0.029	0.033
2	mean	0.123	0.008	0.027	0.075	0.013	0.637
	std dev	0.087	0.001	0.025	0.095	0.013	0.317
	min	0.038	0.005	0.002	0.021	0.000	0.161
	max	0.364	0.010	0.102	0.370	0.041	1.208
3	mean	0.105	0.007	0.015	0.020	0.002	0.090
	std dev	0.060	0.002	0.007	0.008	0.003	0.055
	min	0.008	0.003	0.006	0.009	0.000	0.017
	max	0.216	0.011	0.027	0.035	0.010	0.185
4	mean	0.030	0.007	0.023	0.048	0.006	0.002
	std dev	0.018	0.003	0.013	0.022	0.006	0.006
	min	0.003	0.001	0.001	0.019	0.000	0.000
	max	0.070	0.012	0.043	0.087	0.017	0.019
5	mean	0.073	0.014	0.018	0.024	0.056	0.307
	std dev	0.045	0.005	0.010	0.011	0.013	0.164
	min	0.003	0.009	0.005	0.010	0.038	0.098
	max	0.141	0.025	0.035	0.059	0.093	0.637
6	mean	0.057	0.006	0.000	0.026	0.003	0.014
	std dev	0.037	0.003	0.000	0.012	0.004	0.016
	min	0.012	0.002	0.000	0.010	0.000	0.000
	max	0.147	0.010	0.000	0.048	0.011	0.044
7	mean	0.129	0.006	0.012	0.032	0.022	0.016
	std dev	0.057	0.002	0.006	0.008	0.006	0.022
	min	0.027	0.002	0.002	0.014	0.008	0.000
	max	0.244	0.011	0.023	0.046	0.031	0.090
detection limit (2 sigma)		0.002	0.002	0.008	0.005	0.005	0.010

The following elements were sought but were not consistently above their detection limits: Si, 0.003; Ti, 0.005; V, 0.004; Mn, 0.004; Zn, 0.018 (wt%, 2 sigma).

only visible at several millimetres back from the tips of the cutting edges (*eg* 3mm in No 3, see Fig 2); this may be due to wear or sharpening. These three axeheads are all from waterlogged and related contexts at Fiskerton. It is relevant to note that they have suffered very little deterioration through corrosion — as is common with artifacts from waterlogged deposits — and the evidence of surface-carburization *has* therefore survived. However, in Nos 1 and 2, recovered from waterlogged deposits from other sites, evidence of enhanced carburization was not present or had not survived.

Surface carburization is rarely reported in archaeological artifacts and the effects of corrosion often lead to uncertain identifications. Possible examples of Iron Age date include three swords: Grimthorpe, North Humberside; Whitcombe, Dorset; Stanwick, North Yorkshire (Lang 1987, 62, 71–2,

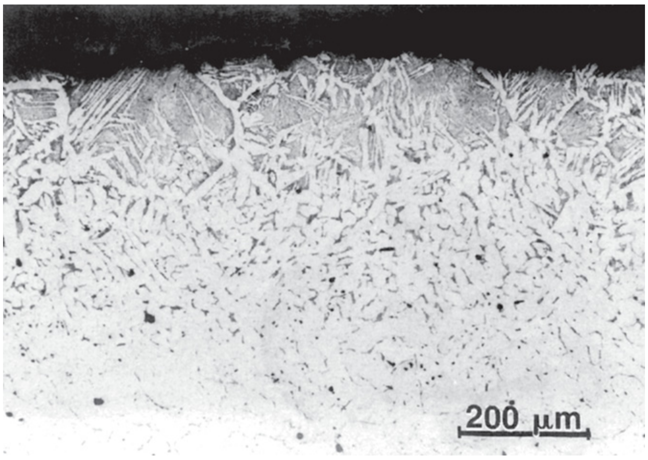

Fig 3: Axehead 3, edge of specimen showing gradient in carbon composition from high at the metal/corrosion interface (top) to low in the interior (lower). Ferrite (light), pearlite (mottled, grey). Nital etch.

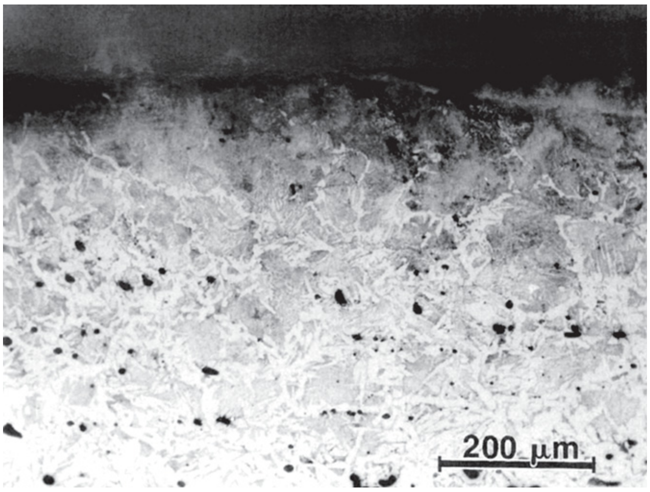

Fig 4: Axehead 4, edge of specimen showing gradient in carbon composition from eutectoid at the metal/corrosion interface (top) to low in the interior. Ferrite (light), pearlite (grey). Nital etch.

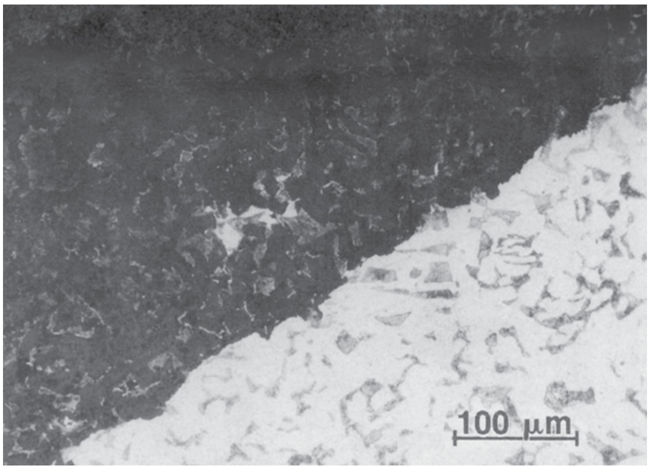

Fig 5: Axehead 5, metal/corrosion interface. Lower right: metal comprising ferrite (light) and pearlite (grey). Upper left: corrosion layer (dark) with remanent carbides from pearlite (light) and isolated ferrite (centre, white). Nital etch.

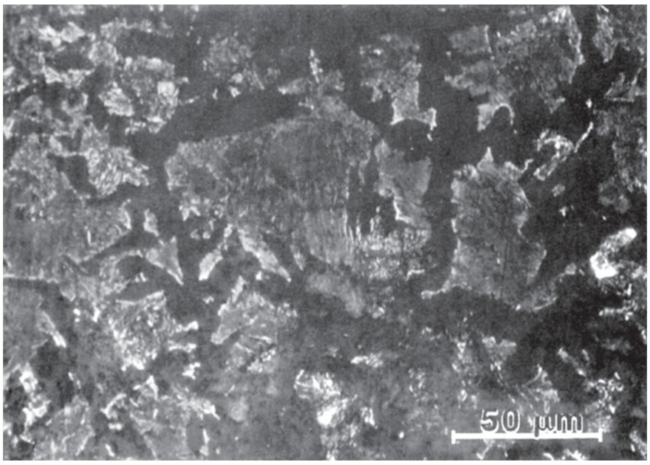

Fig 6: Axehead 5, detail of corrosion products showing high concentration of remanent carbides from pearlite (light) in corrosion products (dark).

nos 10, 14 and 16).

Although no other Iron Age axeheads from England have been examined by metallography as far as the authors are aware, a few have been investigated from elsewhere in the British Isles. A socketed one from Rahoy, Argyll, Scotland contained 0–0.3% carbon (Desch 1938, 41–3). Two socketed and two shaft-hole axeheads from northern Ireland all seem to be technologically more advanced. These have enhanced carburization, either within the central components or at the surface, and three are also quenched (Scott 1990, 49–58, nos 1–4).

Hardness
The cutting edges of the seven axeheads are all of relatively low hardness, even in those with enhanced carburization at the edges, since none had been heat treated. Large and heavy axeheads were presumably felling tools and it may be that resilience and toughness were the principal qualities sought, rather than hard and brittle cutting edges. Certain other types of Iron Age tools have been found to be quench-hardened, some possibly tempered, where different qualities as tools are expected, for example hammers (Fell 1993).

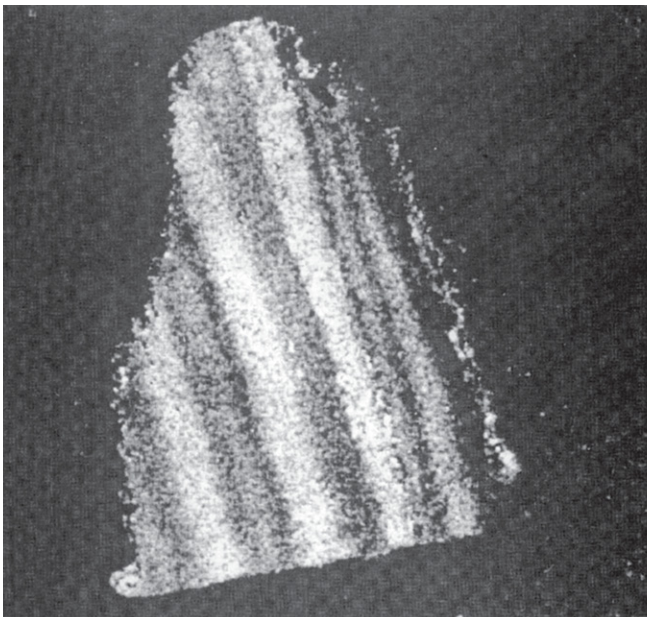

Fig 7: Phosphorus distribution in specimen from axehead 7 (electron microprobe digital map). High phosphorus areas appear light. Scale bar, 0.5mm.

Minor and trace elements
The variable levels of phosphorus and arsenic detectable in several specimens are interpreted as element segregations during metal preparation. Phosphorus segregates during smelting and during smithing of the bloom and products, whereas arsenic can become enriched through surface oxidation during smithing (cf Tylecote and Thomsen 1973). Both elements increase the hardness of ferrite and can cause brittleness — phosphorus at low temperatures, arsenic at high temperatures (*ibid*). However, none of the axeheads displayed particularly high concentrations of either element, but nevertheless, properties were probably modified to some extent.

Conclusions

The carbon compositions of the seven axeheads are well within the normal range for Iron Age artifacts. Two or possibly three axeheads had been surface carburized. None was heat treated, probably because resilience and toughness were the principal qualities sought in the cutting edges, although these properties may have been slightly reduced by the presence of trace elements such as phosphorus in the metal.

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References

Barclay A, Fell V and Wallis J 1995, 'An iron socketed axehead from the River Thames, Buscot, Oxfordshire', *Oxoniensia* 60, 417–9.

Boyd Dawkins W 1902, 'On Bigbury Camp and the Pilgrims' Way', *Archaeological Journal* 59, 211–18.

Coombs D 1992, ‘Flag Fen platform and Fengate Power Station post alignment — the metalwork’, *Antiquity* 66, 504–17.

Desch C H 1938, ‘Report on the axe’, in V G Child and W Thorneycroft, ‘The Vitrified Fort at Rahoy, Morvern, Argyll’, *Proceedings Society Antiquaries Scotland* 72 (1937–38), 23–43.

Ehrenreich R M 1985, *Trade, Technology and the Ironworking Community in the Iron Age of Southern Britain* (Oxford: BAR BS 144).

Fell C I 1936, ‘The Hunsbury Hill-fort, Northants: A new survey of the material’, *Archaeological Journal* 93, 57–100.

Fell V 1990, Pre-Roman Iron Age Metalworking Tools from England and Wales: their Use, Technology, and Archaeological Context. Unpublished M Phil thesis, University of Durham.

Fell V 1993, ‘Examination of four Iron Age ferrous hammer heads from Bredon Hill (Hereford and Worcester), England’, *Historical Metallurgy* 27(2), 60–70.

Field N 1986, ‘An Iron Age Timber Causeway at Fiskerton, Lincolnshire’, *Fenland Research* 3, 49–53.

Field N forthcoming, ‘Excavations at Fiskerton, Lincolnshire’, *Proceedings Prehistoric Society*.

Hedges R E M, Pettitt P B, Bronk Ramsay C and van Klinken G J 1997, ‘Radiocarbon dates from the Oxford AMS system: *Archaeometry* datelist 23’, *Archaeometry* 39(1), 247-62.

Knight D 1984, *Late Bronze Age and Iron Age Settlement in the Nene and Great Ouse Basins* (Oxford: BAR BS 130).

Lang J 1987, ‘The Technology of Celtic Iron Swords’, in B G Scott and H Cleere (eds), *The Crafts of the Blacksmith*, Proceedings 1984 Symposium UISPP Comité pour la Sidérurgie Ancienne (Belfast), 61–72.

Manning W H and Saunders S 1972, ‘A Socketed Iron Axe from Maids Moreton, Buckinghamshire, with a Note on the Type’, *Antiquaries Journal* 52(2), 276–92.

Salter C J and Hedges R E M 1979, ‘Source determination of iron currency bars through analysis of the slag inclusions’, *Archaeometry* 21(2), 161–75.

Scott B G 1990, *Early Irish Ironworking* (Belfast).

Stead I M 1985, *Celtic Art in Britain before the Roman Conquest* (London).

Thompson F H 1983, ‘Excavations at Bigberry, near Canterbury, 1979–80’, *Antiquaries Journal* 63(2), 237–78.

Tylecote R F and Thomsen R 1973, ‘The segregation and surface-enrichment of arsenic and phosphorus in early iron artifacts’, *Archaeometry* 15(2), 193–8.

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