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The Anglo-Saxon cemetery at Dover Buckland, Kent, UK and the technology of some of the iron artefacts.

Summary

Excavation of an Anglo-Saxon cemetery at Buckland, Dover, UK yielded several weapon burials (5th century to AD 600). After radiography at the British Museum, five swords, four spearheads, a weaving batten and a shield boss apex were sampled for metallography and analysis. This showed that the swords and batten were pattern-welded with low carbon iron and phosphoric iron. Three had steel edges, two of which were tempered martensite. Two swords had ferritic edges and one of these had welds enriched with arsenic and nickel, suggesting a different ore source. One spearhead was steel, the others were hetereogenous bloomery iron. Four of the seven shield bosses had a thread-like unfused cavity in their apices. Both the technology (two swords had ground fullers) and the burial contexts suggest cross-Channel contacts.

Introduction

A large Anglo-Saxon cemetery in the Buckland area of Dover, Kent, SE England, was partly excavated by Vera Evison (Buckland I) in 1951 - 1953 and the remaining part (Buckland II) was excavated by Keith Parfitt (Canterbury Archaeological Trust) in 1994. Buckland II yielded 244 graves, almost three-quarters of which contained grave goods dating from the late 5th century to AD 600 (Parfitt & Anderson 2012). The iron objects included seven swords, a sword-like weaving batten (used to push down and consolidate the weft in weaving), twenty-four spearheads and seven shield bosses. All objects were radiographed. Mounted samples from a number of the objects were investigated at the British Museum (Department of Science and Conservation), using a Zeiss reflected light optical microscope, a JEOL scanning elec- M) equipped with an Oxford ISIS energy dispersiveXray analysis facility (EDX), a Vickers diamond pyramid hardness tester (100 g load). Some microanalyses of inclusions and the body metal were obtained using the SEM-EDX system. The precision is taken to be 2 sigma (1.5 % for iron and less than 0.5 % for other elements. The accuracy was ± 1 - 2 % and the detection limits less than 0.07 % for all elements except iron (Wayman et al. 2004, Lang 2012, 238). Samples are referred to by their grave numbers, e.g. Gr 264.

Shield bosses

Warriors held their wooden shields with a grip or bar on the inside and the hand was accommodated by a hole in the shield. This was protected on the outside by a conical metal boss. The form of the shield bosses varies in detail, but viewed from the side, each consists of a metal cone with a near-vertical wall that flares out at the bottom into a horizontal flange. This is attached to the shield with rivets. The top of the cone was formed into a flat topped, button shaped apex (for details see Dickinson & Harke 1992). The seven shield bosses did not show the repairs, additions or joins between the flanges, walls, cones or apices found in other bosses by Harke & Salter (1984). The boss apices from graves 264, 265b, 323 and 414 appeared to have tiny cavities running from inside the cone through to the top surface of the apex. The detached apex of the boss from Grave 323 was examined metallographically. A cross section confirmed that the thread-like cavity runs from the inside of the boss to the top surface of the apex and that the metal had not been fused.

The metal was a heterogeneous phosphoric iron. Shield bosses require extensive forging, so a malleable material with tough impact resistance in use is desirable. Phosphoric iron might not appear to be an obvious choice. Nowadays phosphorus is always avoided in iron, as it causes temper brittleness by segregating at the grain boundaries if the metal is heated or slowly cooled between 375 °C and 575 °C. However, studies by Goodway & Fisher (1988), Crew & Salter (1993) and Godfrey et al. (2005) have shown that phosphoric iron can be forged successfully and air cooling avoids the danger of segregation, so it would have been suitable.

Harke & Salter (1984) suggested that shield bosses could either be forged from a single billet or by making the cone and wall separately and then welding them together. Neither method would have produced incompletely fused apices. It is suggested that a rectangular sheet was welded into a cylinder (it is often difficult to detect a weld after multiple forging cycles), one edge was forged to make the flange and the other extended inwards, to make the cone and the edge was crimped to make the apex. The bosses from graves 264, 265B, 323 and 414 were probably made in the same way as they also show apex cavities. The directional working produces a fibered structure in the neck, increasing its impact resistance.

Striations were visible in the apices of bosses from Tranmer House on X-radiographs, but a cross-section showed that cavities within the neck did not penetrate to the upper surface of the apex (Lang & Wang forthcoming). This boss was probably forged from a disc shape into a flanged cone. The internal angle of the cone was decreased until the metal could finally be crimped together to make the apex. Evidently different methods of shield boss construction were followed at different sites or workshops and making bosses might have been a specialised activity.

Spearheads

The four spearheads differ in size and shape, but are essentially simple in design, with short or negligible shanks. X-radiographs did not show welds or patterns but some appeared to be layered or piled, while others did not. It is not easy to distinguish between metal originally welded together from separate pieces (possibly with different compositions) and well- worked but inhomogeneous bloomery iron in which areas slightly richer in carbon or phosphorus have been elongated by working, giving the appearance of layers. Microsections were taken from the spearheads in graves 264 and 299 (apparently 'piled') and from spearheads in graves 323 and 393A (apparently without layers). The sections showed that (with the exception of Gr 323), the spearheads were made from somewhat inhomogeneous wrought iron with a little carbon and phosphorus. Neither of the 'piled' blades (Gr 264, Gr 299) had recognisable layers. However, relatively large inclusions were strung out irregularly from the middle of the blade towards the edge which may have given the appearance of a piled structure on the radiographs. Conversely, Gr 393A appears 'plain' on the X-radiograph, but the cross-section showed a layered or piled structure. Its carbon content increased slightly towards the surface, but with little increase in hardness. The fourth section, Gr 323, (apart from a split, not visible on the X-radiograph) was a good quality steel, suitable for the wide, thin blade, which tapered to a point. It is harder overall (290 - 382 Hv $_{01}$) than the other spearheads (165 - 260 Hv $_{01}$ maximum values), and despite being relatively thin, would have retained its shape well.

Apart from some hardened Anglian spearheads from West Heslerton, Yorkshire, (Moir 1990), and welded spearheads (one was patternwelded) at Saltwood (Riddler 2006), comparison with spearheads from cemeteries at Edix Hill (Barrington A) (Gilmour & Salter 1998), Boss Hall (Fell & Starley 1999), Flixton (Lang 2012), and Tranmer House, Sutton Hoo (Lang & Wang forthcoming), leads to the conclusion that the quality of material and construction used for spearheads was poor in comparison with other iron blades. Such spearheads may have been intended for 'non-functional symbolic purposes' as Fell and Starley suggest, but the requirements for spearheads were probably less stringent than for other weapons and cutting tools. Less than half of the edges of the Edix Hill spearheads were hardened or were steel, whereas, in comparison, about two-thirds of the knives from the same site had harder edges and more than half contained steel.

There is little correspondence between the categories assigned using established spearhead typologies (Swanton 1974) and the technology. For example, of three D2 type spearheads recently examined, two were inhomogeneous wrought iron with phosphorous (Buckland Gr 264, Tranmer House Gr 967), while the third (Tranmer House 857), had three layers, including a core layer with 0.3 - 0.4% C. There was no correlation between the typology and technology of the Saltwood spearheads either (Riddler 2006, 31).

Five swords and a weaving batten

X-Radiography showed that all the swords and the weaving batten had patternwelded central panels (Fig. 1). Examination of half-blade sections from five of the seven swords and the batten showed that the panels were constructed by firewelding together strips of phosphoric iron (P content > 0.07 %, the detectable limit) and low carbon iron (C content <0.1 Samuels 1980, 59) or mild steel (C content max 0.25 % Samuels 1980, 570) which would respond differently when the finished sword was etched (Fig. 2). The composition of Gr 346 is unusual as the welds are enriched with arsenic and nickel and little or no carbon is present. The phosphorus-rich bands have larger grain sizes (Fig. 3). From the occasional presence of silica in welds (Gr 264), it can be inferred that sand was sometimes used as a flux during welding. Plain core layers were sandwiched between the patterned layers in Gr 346, possibly also Gr 347 and the weaving batten (Grave 250). The multilayered core of Gr 264 is very unusual (Fig. 2). Cores probably added strength and toughness especially if the patterned layers were relatively thin, or if the welds were unsound.

X-radiographs show that separate edges were welded on and often extended around slightly elongated patternwelded central sectors to make the tangs and blade

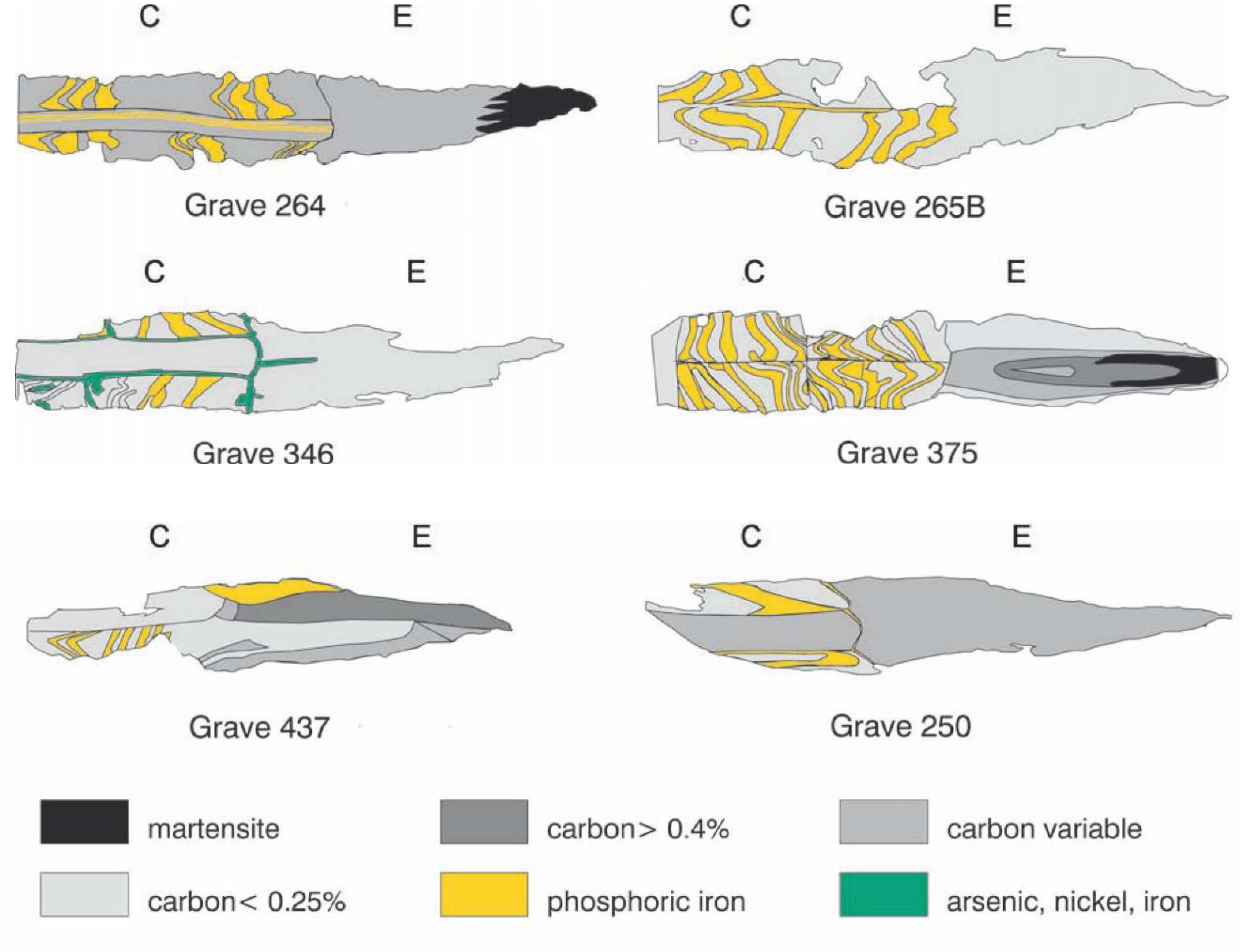

Fig. 1: Diagram of half-blade cross sections of the swords and weaving batten (not to scale) showing the distribution of carbon, phosphorus and the martensitic phase. Arsenic and nickel contents are mapped in the sword section from grave 346.

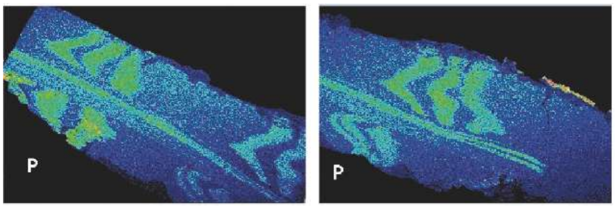

Figure 2: Sword from Buckland grave 264 (width of field 10 mm). SEM-EDX phosphorus distribution map.

tips, leaving a small cavity which is visible. The same configuration, (without the hole), could be seen at bottom of the batten. This type of batten is sometimes thought to be a cut-down or re-used broken sword, but the radiographs demonstrate that it had not been reused in that way.

The edge strips of the swords were sometimes composite: Gr 437 has three or four layers, including both phosphoric iron and steel (C content > 0.25 %), the latter forming the actual cutting edge.

Figure 3: Sword from Buckland grave 346 (21 1021 x10: width of field 1.36 mm)
Part of the pattern welded central section with slag particles and consisting of bands of large grained phosphoric iron and low carbon iron of mixed grain size.

Steel edges meant that heat treatment could be used. Rapid cooling resulted in an extremely fine, hard and

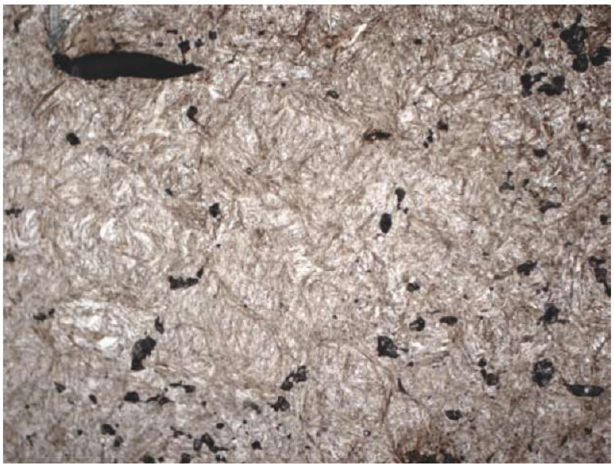

Figure 4: Sword from Buckland grave 264 (11 1019 x 50: width of field 0.27 mm). Near the cutting edge, martensite , possibly bainite, with inclusions and small areas of pearlite

tough pearlitic structure in Gr 437. Two swords (Gr 264, Gr 375) have edges with rapid-etching quenched structures (martensite and possibly bainite) (Fig. 4). They may have been slack quenched (i.e. quenched from above 730 ° C into water and then withdrawn quickly, so that the residual heat tempered core of the blade, increasing impact resistance). The batten edge was made from eutectoid steel, but unsurprisingly, was not quenched. Hardness varied considerably between the swords (Table 1).

Two swords (graves 264 and 265B) appear to have fullers or 'blood channels' down the middle of the blade. These can be either forged or ground. The radiographs show hints of curving patterns which is consistent with removal of the surface during grinding (Anstee & Biek 1961). The sections Gr 346 and Gr 375 showed slight depressions in the middle of the blade which may be the remains of forged fullers (curving elements are absent), but corrosion has removed the surfaces and any traces of distortion. The blades showed no uniformity, but generally resembled other published Anglo-Saxon blades (e.g., Gilmour 2007).

Discussion

The artefacts were made from inhomogeneous wrought iron, low carbon iron, phosphoric iron and steel (up to 0.8 % C). Ironstone is found in Kent and the nearest substantial ore source is the carbonate (siderite) deposit in the Weald, SE England. Phosphoric iron was probably made from bog iron ore, which is frequently rich in phosphorus (Crew & Charlton 2007) and manganese (Buchwald 2005, 235) but there are few, if any, local sources. Steel occurs as carbon-rich areas in blooms (Gassman 1998; Buchwald 2005), and was probably utilised from the Iron Age onwards. It is clear that early medieval smiths could discriminate between various ferrous alloys (Thalin Bergman & Arrhenius 2005, 79; Gilmour 2007, 2010). Cast iron has also been found at a number of early sites, (Tylecote 1986, 167; Fluzin 1999) and Mack et al. (2000) have suggested that steel was produced from cast iron in Saxon Southampton. Both methods may have been used contemporaneously.

The composition of sword Gr 346, (nickel and arsenic content concentration in the welds) suggests a different ore source. Weathered iron-bearing marcasite nodules were exploited by early iron makers according to Ty-

Table 1 Summary of metallographic results

grave	object	alloys	carb.	layers	core	mart.	heat treatment	Centre HV0.1	Edge HV0.1
264	sword	LC, MS, Pl, S		2p	y	y	quench, temper	170-310	260-500+
265B	sword	WI, LC, Pl	y	2p			none	130-236	130-177
346	sword	WI, LC, Pl#		2p	y		none	143-207	133-195
375	sword	LC, Pl, S		2p		y	quench, temper	151-490	119-490+
437	sword	LC, Pl, S		?2p	y?		quench, temper	127-215	171-520
250	batten	MS Pl S		2p	y		none	156-248	289-374
264	spear	LC, Pl, WI		H			none	211	260
299	spear	Pl WI					none	147	203
323	spear	S		?2			none	290	382
393A	spear	LC, Pl, WI	y	H			none	146	165
323	boss apex	LC, Pl					part anneal		

Table 1: Summary of metallographic results of artefacts from the Anglo-Saxon cemetery at Dover Buckland, Kent.
Abbrevations: LC = low carbon iron (C < 0.1 %); MS = mild steel (C max. 0.25 %) ; Pl = phosphoric iron (P > 0.07 % = limit of detection); S = steel (C > 0.25 %); # = Ni and As in weld; p = patternwelded; y = present; mart = martensite; Hv_{01} = diamond pyramid microhardness 100 g (iron and steel definitions: Samuels 1980).

lecote & Clough (1983). These nodules often contain traces of arsenic and nickel and are found in chalk (including the cliffs at Dover), but published evidence of their exploitation is lacking. Bog ore is another possibility: Navasaitis et al. (2010) found concentrations of arsenic, nickel, cobalt and phosphorus in the bloomery products of Lithuanian bog ores. In any case, it was not possible to identify the sources of the metal because the resources were not available to carry out REE analysis, as described by Dillman & l'Héritier (2007) and the material was unsuitable for applying the rigorous criteria for slag inclusion analysis set out by Desaulty et al. (2009).

The finished artefacts contain material introduced during extraction and smithing from the ore, fuel, furnace linings and flux (if used). Some elements reduce into the metal (nickel) while others (phosphorus, arsenic, manganese, sulphur and silicon) may reduce into both metal and slag, depending on the conditions. Fragments of magnesia, alumina, silica or lime (MgO, Al_2O_3 SiO_2, CaO), essential for the extraction processes, are not reduced and are retained in the metal as inclusions (Dillman & L'Héritier 2007; Blakelock et al. 2009). Theoretically it should be possible to compare the compositions of different components in each sword to identify those from the same stock. Unfortunately, although 600 analyses were made, the results for each component were not sufficient to allow meaningful statistical analysis to be carried out.

The average values of the analysis results from the central and edge sectors are compared in Table 2. The average silica, lime (except Gr 375) and manganese (except Gr 437) contents of the inclusions were higher in the edge sectors of the swords, while the average alumina content (except Gr 346) was higher in the central sectors. The small but consistent differences in inclusion composition between the central and edge sectors can be attributed to the greater number of cycles of forging and welding the central sectors were subjected to, so that a higher proportion of the gangue minerals were eliminated as slag, in accord with the findings of Hedges and Salter (1979) who suggested that as the most heavily worked currency bars in their study contained fewer, smaller inclusions than those which were less worked, material had been lost during the smithing process rather than added. The alumina content, however, is higher in all the central section inclusions (except Gr 346): it is most likely to have come from the lining of the smithing hearth (Blakelock et al. 2009).

The SEM element maps show that phosphorus is distributed widely but more diffusely in the central sectors of Gr 265B and Gr 437, making the patterns difficult to distinguish radiographically. Individual components in some of the sword sections contained trace amounts of elements such as nickel (in the metal), or arsenic (unusually, in both slag and metal in Gr 346), which other components of the same sword do not. Similarly, barium, chromium, cobalt or vanadium occurred in the inclusions of some components in the same sword samples, but not others, suggesting that some components may have come from the same stock while others came from a different source. Analysis of the weaving batten inclusions, for example, showed that half the components have traces of barium (0.5 - 0.9 % BaO) in their inclusions, while the other half did not. Two of the core layers and one of the twists of Gr 264 contain up to 0.6 % Ni, which is absent in the other components.

Table 2 Comparison of Inclusion Composition in centre and edge sectors

Grave	Location	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO	TiO2	MnO	FeO	V2O5	Cr2O3	CoO	As2O3	BaO
Gr 264	centre	0,7	12,0	48,9	1,4	0,1	1,5	3,2	0,5	0,8	32,2					
	edge	0,7	10,7	55,7	1,2	0,1	1,4	4,5	0,7	0,9	23,3			0,1		
Gr265B	centre	1,2	24,7	30,5	0,6		1,3	2,2	0,3	0,3	36,0	0,1	0,2		0,3	
	edge	0,3	10,2	33,6	1,3	0,3	1,0	3,4	0,5	1,4	47,2					
Gr 346	centre	0,5	4,7	20,8	3,4	0,1	0,9	1,3	0,2	1,4	66,2		0,1			0,1
	edge	0,8	10,1	33,1	2,6		2,3	4,0	0,4	4,3	39,3	0,1			0,1	0,5
Gr 375	centre	0,5	2,9	21,6	6,7	0,2	1,2	2,8	0,2	0,1	63,1					
	edge	0,8	2,2	47,2	1,0		1,2	2,4	0,2	3,7	44,1			0,1		
Gr 457	centre	0,4	5,7	33,5	1,4	0,1	0,9	2,4	0,3	0,5	77,3			0,1		
	edge	0,4	3,2	41,0	2,6	0,0	1,4	3,1	0,2	0,2	46,7			0,1		
Gr 250	centre	1,3	9,8	54,6	0,1	0,0	1,3	1,3	0,6	0,3	28,8					
	edge	1,5	11,5	64,7	0,1	0,0	1,5	1,6	0,7	0,4	16,2					

Table 2: Comparison of inclusion compositions in the center and at edge sectors of the artefacts from various graves of the cemetery at Dover Buckland, Kent. Gaps: not detected by SEM

McDonnell (1988) suggested that because manganese minerals are not found in refractories flux or fuel ash in great quantities, inclusions which contained more than 0.5 % MnO come from the ore rather than the fuel ash. On this basis, the MnO content in the swords and the batten came mainly come from the ore, although as a caveat, it should be mentioned that Joosten et al. (1996) suggested that manganese rich minerals were used as a flux during the Migration Period. Also, some wood ash (e.g., birch) may contain up to 5 % MnO (Evans & Tylecote 1967).

Clearly, alloy selection and fabrication, using firewelding, carburisation and heat treatment were known and in varying degrees practiced by smiths. The sample is too small and the time span too short to see convincing evidence of technical progression or change.

Thálin Bergman & Arrhenius (2005) have suggested that patternwelding was developed for practical reasons, to utilise the small pieces of metal available, and then it became an art, conferring status on the smith and his client. Introduced during the Iron Age (Pleiner 1993), its greatest popularity was during the Roman Imperial and early medieval periods when it was used mainly for sword making, but also for decorating high status objects such as axes, some knives and weaving battens. Patternwelding has been extensively studied by Tylecote & Gilmour (1986), Lang & Ager (1989), Buchwald (2005) and Gilmour (2007, 2010), amongst others. Usually strips of phosphoric and low carbon iron were welded together and then twisted. Three or four of these composite bars could be welded together to make one layer, usually the central panel of a sword. Twisting might be from end to end, or as alternating straight and twisted sections. The twists might be aligned or opposed across the width and in both layers. In practice, twisting was not always even and the sword from Grave 249 (not sectioned) has one patterned layer within which the alternating straights near the hilt were 20mm longer in one layer than the other. The smith corrected this by reducing the length of the straights, until at about 270 mm from the hilt, the twists coincided on both sides. Patterns were normally the same in both layers, but the weaving batten has a pattern on one side made from two twisted bars and on the other, three bars with twisted and straight sections.

Hardness tests show little difference between the hardness values of the phosphoric iron and the low carbon strips, so resistance to scratching and wear is similar. Without mechanical tests it is difficult to judge the effect of deformation. Mechanical tests indicate that if the welds are sound, composite structures of wrought iron and mild steel are more resistant to impact and bending stresses than low carbon iron and wrought iron on their own, but less effective than steel (Lang 2011).

The curving patterns revealed by grinding away the surface (Anstee & Biek 1961) are seen more frequently on continental swords (Lang and Ager 1989; Gilmour 2010), which implies that the blades may have been imported. Vince Evans, an experienced modern experimental swordsmith, has demonstrated that curving patterns can also be produced by splitting a composite layer of twisted bars, using ordinary blacksmiths' tools, to make two strips showing curving patterns (personal communication).

Carbon-rich components were used but surface carburisation was more difficult to identify, because corrosion has removed the surface layers, but increased carbon contents at the cutting edges of Gr. 265B and the spearhead Gr 393A suggest carburisation did take place.
Function is intertwined with social and cultural contexts. Patternwelding is an example: during the time of the Buckland cemetery, it was widely used, but by the 10th century it had virtually died out. It was expensive in both time and resources (a considerable amount of metal is lost as oxide during the welding and forging processes) and it seems likely that it was overtaken by the increased availability of good quality steel, possibly some crucible steel (Williams 2007), the fashion for the signature swords (ULFBERHT etc) and also, perhaps, a change in the socio-economic position of smiths and the rise of Christianity may also have played a part in the changing symbolism of swords.

The cemetery provides a wider context, demonstrating that the community was prosperous: the skeletal remains show that the average height was the same as current Kentish residents and there were few signs of poor nutrition, so rich burials, including weapon sets, are not unexpected. Bone preservation was poor but there is little to suggest that the occupants of the weapon burials were particularly robust or showed specialised muscular development. None of the sword bearers showed any signs of injury, perhaps surprisingly, and the corroded state of the swords makes it difficult to see any signs of wear on the weapons themselves.

Conclusions

The grave goods and their disposition in the weapon burials strongly suggest cross-Channel contacts. Two of the graves (Gr 264, Gr 265B) contain swords with fullers made in the Continental style, but of different quality: sword Gr 264 has a multicore layer and a quenched and tempered cutting edge, whereas sword Gr 265B lacks a core and the edge is soft iron. Grave 265B also contained a fine decorated continental belt set and a balance, numerous Roman coins used as weights, scraps of metal, all of which suggests the occupant might have been a trader. His sword would have looked well, befitting his status but it would not have been as effective a weapon as the sword in nearby grave 264. Perhaps the deterrent value of a fine looking patternwelded sword should not be underrated. Both graves contain shield bosses with unfused apices (also Grave 414 and Grave 323, where the steel spearhead was found). These four shield bosses are categorised as type 3 (Dickinson & Harke 1992; Spain 2012), a Merovingian form, thought to have been originally imported from the Continent and often found in Kent. The construction of the four suggests that they came from the same workshop tradition. It may be indicative of ritual that in each of the three graves with shields with unfused apices, the accompanying sword and spear are placed on the same (left) side of the body, whereas in the other weapon graves they are placed on either side. The inclusion of shields in burials is uncommon on the Continent and there were two sword burials without them Grave 249 (not examined metallographically) and Grave 346 included the sword with arsenic and nickel and also an axe. The sword from Grave 437 (with the composite edge) was accompanied by a fauchard and glass bowl, suggesting a Frankish association.

Harke (1992) has remarked that 'all weapon sets found in Anglo-Saxon burials cannot have been the result of functional considerations...analysis suggests that the weapons were a largely symbolic burial deposit', but the objects themselves have information to impart. Without specialised slag inclusion and tooth enamel analysis it is not possible to know where the metal or the men buried in the weapon graves came from, or where their weapons were acquired, but they help to show that the proximity of Dover to mainland Europe allowed the exchange of material goods, customs and individuals to take place.

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