Ancient Monuments Laboratory
Report 137/87

ANALYSES OF EIGHT IRON KNIVES AND FOUR OTHER TOOLS FROM HAMWIH, SOUTHAMPTON.

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Summary

A further eight Anglo-Saxon knives were sectioned to confirm earlier analyses (HBMCE Report 93/87). The results were similar, in general the knives were manufactured from ferritic, rather than phosphoric iron, and good quality steel cutting edges were butt welded to the knife backs (Type 2 manufacture). A billhook, two chisels and an axe were also analysed.

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THE ANALYSIS OF EIGHT IRON KNIVES AND FOUR TOOLS FROM HAMWIH, SOUTHAMPTON

A second group of knives were selected to complement the earlier report (AML Report 93/87). Since the first report all the knives from the Six Dials Sites had been classified, typologically and with reference to details obtained from X-radiographs. This enabled all the knife types to be examined metallurgically. Four tools were selected for analysis to investigate whether the methods of knife manufacture were utilised in other edged tools. The hardness results given in this report utilised 100gmf for micro-hardness's (uHv) and 5Kgf for Vicker's Hardness (Hv).

1 KNIFE 31/340

Knife 31/340 was ascribed to Typological Group A. It was 109mm long with a maximum width of 11mm. The knife was heavily corroded in the area of the (probable) tang/blade interface (Type A knives lack a Tang/Blade shoulder). X-Radiography (Figure 1) confirmed corrosion penetration at this point, and complete corrosion of the knife tip and of the tang. The corrosion ended abruptly, 28mm from the tang end. Therefore, the corrosion pattern may have resulted from the nature of the handle. One probable weld line was present indicating that the cutting edge was butt welded to the knife back. The cutting edge had the typical steel radiographic pattern, but the knife back lacked the characteristic fibrous 'wrought iron' radiographic pattern. Two sections were removed from the knife (Figure 1).

In the unetched condition very few slag inclusions were present in either section, and there was no banding visible. In the etched condition both sections were quenched hyper-eutectoid steels with martensite plus retained austenite in the centre of the blade (uHv=642) degrading to tempered martensite at the edges (uHv=572). The relatively low hardness of the centre was due to the high percentage of retained austenite. There was evidence that some austenite had transformed to martensite, after heat-treatment, i.e. during burial, austenite being unstable at ambient temperatures. The high austenite content indicated a high carbon content.

The knife was manufactured from a single piece of steel, it therefore belongs to Manufacturing Typology 3. It was a high quality knife, rapidly quenched.

The absence of the probable weld line observed in the X-radiograph cannot be explained, unless the two sections did not overlap and the weld was between the two sections. The absence of the typical 'fibrous wrought iron' radiograph pattern for the back section was due to its all steel manufacture.

2 KNIFE 31/663

Knife 31/663 was ascribed to Typological Group B, the back of the blade sloping sharply down to meet the tip, and there was no distinct tang/blade interface. It was 92mm long with a maximum width of 11mm. X-Radiographs showed corrosion throughout the knife, and a possible weld line near the cutting edge, which appeared to be more apparent in the tang (Figure 2). All the metal had the steel corrosion pattern rather than the fibrous 'wrought iron' pattern. It was therefore possible that the blade was manufactured wholly from steel. Two sections were removed (Figure 2).

The unetched condition showed that one side of the knife back was heavily corroded, and that there were quench cracks present. There was a slag line running diagonally across the section. The cutting edge section showed a complex pattern of slag lines, again a diagonal band was apparent, with probable piling on one side. There was a possible transverse butt weld line near the tip, below which the slag inclusions showed a tendancy to vertical banding. In the etched condition (Figure 3), the butt welded structure of the knife was confirmed. The cutting edge had a pearlite plus ferrite microstructure indicating that the knife had not been quenched. There was carbon diffusion across the weld line into the knife back. The diagonal weld line present in the knife back of both sections had a carburised zone associated with it, ranging from pearlite to bainite. The knife back was characterised by the presence of a phase at the ferrite grain boundaries, providing a network throughout the knife back (Plate 1). In some areas the network became dominant. The ferrite grains were very large (generally ASTMS 1 or larger, although some areas had grain size ASTMS4-5), and had rounded edges, indicating high temperatures, perhaps melting. The grain boundary phase was nucleated on the slag inclusions, and showed widmanstatten characteristics. Analysis of the grain boundary phase (Table 1) showed high phosphorus contents and in other parts an enhanced nickel content. The tip had a high phosphorus content for a steel, but the analysis may have derived from a ferritic rather than a pearlitic area of the cutting edge.

TABLE 1 CHEMICAL ANALYSIS OF KNIFE 31/663

	%P	%Cu	%Ni
Grain Boundary Phase	0.2	0.1	0.4
" " "	1.0	n.d	n.d
" " "	0.8	n.d	n.d
Ferrite(?) Grains	0.2	n.d	n.d
Cutting Edge (Steel)	0.3	0.1	0.1

n.d - not determined

The hardness values are given in Table 2, and show that the hardness of the ferrite(?) grains do not differ significantly from those of the grain boundary phase. The results obtained for the tip confirm its pearlitic structure.

The exact composition and cause of the grain boundary phase is not clear. Phosphorus is probably the most important constituent, but nickel (and perhaps arsenic?) may contribute to its formation.

TABLE 2 KNIFE 31/663 HARDNESS VALUES

	uHv	Hv
Knife Back		
Ferrite	192	192
Grain Boundary Phase	162	
" " "	198	
Carbon Diffusion into Knife Back	174	
Cutting Edge		
Ferrite plus Pearlite	172	174
Pearlite	322	

The presence of the grain boundary phase and the poor quality of the cutting edge, despite it being butt welded sets this knife apart from the others.

3 KNIFE 169/417

Knife 169/417 was ascribed to Typological Group B (the back of the blade sloping sharply down to the tip, but it had a possible slight shoulder on the back at the tang/blade interface). It was 150mm long with a maximum width of 11mm. X-Radiographs (Figure 4) showed that the tip and the tang end had suffered extensive corrosion. The uncorroded areas showed that the knife was of butt weld manufacture, the cutting edge having the characteristic steel texture and the knife back showing the typical 'wrought iron' fibrous texture. Two sections were removed (Figure 4).

In the unetched condition the knife back showed inverted 'U-shaped' slag lines indicative of piling or banding. In the edge section there were vertically orientated slag lines, and a possible transverse butt weld line. Above the weld line the slag inclusions were large while those below it, were smaller and more finely distributed. In the etched condition (Figure 5) the butt weld showed as a white/yellow weld line (normally due to the enrichment of nickel and/or arsenic). Below the weld line the cutting edge had a tempered martensitic structure at the tip, which degraded to pearlite at the weld line. A vertically orientated white/yellow weld line extended up from the tip but did not reach the transverse butt weld line. Carbon diffusion had occurred across the transverse weld line into the knife back. The knife back was ferritic with some pearlite present. There were no distinct bands of different microstructure as suggested by the slag lines, but there were variations, some areas having ferrite plus pearlite structures. The ferrite grain size showed considerable variation ranging from ASTMS 4-7. Near to the weld line greater variation was observed, the range being ASTMS 3-7.

The hardness values (Table 3) show variation in the ferrite hardness (uHv 124-168), indicating inconsistent (low) levels of phosphorus.

TABLE 3 KNIFE 169/417 HARDNESS VALUES

	uhv	Hv
Knife Back		
Ferrite	168	169
Pearlite plus Widmanstatten Ferrite	176	
Pearlite	238	
Ferrite	124	
Carbon Diffusion Zone (Pearlitic)	216	
Cutting Edge		
Martensite plus Fine Nodular Pearlite	542	
Tempered Martensite	441	603

4 KNIFE 169/540

Knife 169/540 was ascribed to Typological Group G, because the tip was broken off, although the X-radiographs indicated that the back sloped down towards the tip, i.e. Type E. The knife was heavily encrusted with corrosion products. The X-radiographs confirmed the extent of the corrosion (Figure 6), particularily of the cutting edge, although a probable butt/scarf weld line was apparent. The knife had been incised with a groove, but it was not visible on the radiographs. Two sections were removed from between the areas of the most corrosion (Figure 6).

In the unetched condition a distinct slag line running at a slight diagonal through the back section was apparent. It extended into the cutting edge section (the two sections overlapped). There were small transverse cracks in the knife back, which were often stepped (cf. Hick Cracks). At the top of the knife back was an area of clean metal, i.e. slag free, but there was no evidence of any weld line delineating this area from the rest of the knife. There was a transverse line of fine slag inclusions indicative of a knife back/cutting edge, butt weld. In the etched condition (Figure 7) there was no difference in microstructure on either side of the central slag line, both being ferritic (Grain Size ASTMS 1-2), some areas contained fine inclusions (age hardening carbides?). Nor was there any difference between the ferrite of the clean area and the remainder. Segregating around the slag inclusions was a carbide? phase (or phosphide?). There was some localised areas of ferrite plus pearlite. The transverse weld line observed in the unetched condition was confirmed by the presence of a white weld line. Carbon diffusion had occurred across this weld, giving bainitic and pearlitic microstructures. The cutting edge was a slack quenched tempered martensitic hypo-eutectoid steel.

The hardness results (Table 4) indicate the presence of some phosphorus present in the ferrite, and an efficient cutting edge.

The analysis shows the knife to have been of Manufacturing Type 2. Low phosphorus ferritic iron had been used for the knife back. The steel cutting edge had been butt welded to the knife back. The knife had been slack quenched, and was of overall good quality.

TABLE 3 KNIFE 169/540 HARDNESS RESULTS

	uHv	Hv
Knife Back		
Clean Ferrite	180	218
Ferrite plus Fine Inclusions	159	143
Carbon Diffusion Zone	172	210
Cutting Edge		
Tempered Martensite	612	644

5 KNIFE 169/558

Knife 169/558 could not be ascribed to a single typological group, it had an angled back, but had no distinct tang. Therefore it was ascribed to Type F/B. It was 140mm long with a maximum height of 18mm. The knife was heavily corroded, and X-radiography showed a crack running the full height of the blade (Figure 8), and that the majority of the knife had been heavily corroded. There were changes in the density of the radiograph that may have indicated thickening of the knife or corrosion resistance of different irons that could be interpreted as evidence for a possible weld line between the two irons. If so, it was high up the knife back, and therefore different from any previous butt welds.

There was only one area suitable for sectioning due to the extensive corrosion. During cutting the knife broke and therefore the opportunity was taken to obtain a complete cross-section. The section was corroded but a complete section was obtained. In the unetched condition an inverted "V-shaped" weld line delineated by slag inclusions was visible approximately two thirds of the distance up the section. Above the weld line the iron contained vertically orientated slag lines, giving a slight banding effect. Below the weld line there were fewer slag inclusions, which also showed vertical orientation and a tendancy towards banding. In the etched condition (Figure 9) the iron above the weld line was ferritic with hardness values of uHv=155, Hv=153, which indicate very low phosphorus contents, and the grain size varied bewteen ASTMS 4 - 6. Below the weld line the cutting edge was manufactured from a medium carbon steel that had been slack quenched to give a tempered martensitic structure (uHv=446, Hv=813). The carbon content varied, one small area was ferritic, and there was a vertically orientated banding effect of varying carbon content, possibly induced by the presence of other elements. There had been carbon diffusion across the weld line into the knife back.

Knife 169/558 was ascribed to Manufacturing Type 2, although the weld was not a butt or a scarf weld. A more distinct "V-shaped" weld line would be interpreted as a tongued Type 1 method of manufacture, i.e. the steel cutting edge inserted as a tongue into the knife back. The irons used (ferritic iron and steel) and the welding were of good quality, resulting in a good quality knife. It is distinguished from the majority of other knives analysed by its morphological typology and its inverted "V-shaped" weld.

6 KNIFE 169/1617

Knife 1169/1617 was ascribed to morphological Type D. It was incomplete the tang having been broken off. It had a surviving length of 72mm and a maximum height of 8mm. It had a groove down one side only. It was corroded, especially at the knife back near the tip. X-Radiography showed (Figure 10) that total corrosion penetration had occurred at this point. There was a weld line present dividing the fibrous iron from the steel cuting edge.

Two half sections were removed (Figure 10), the back section incorporating the groove. There was a transverse butt weld present in the knife back section, the cutting edge iron had two vertically orientated lines of fine slag inclusions. Near to the weld line they folded in towards the centre indicating some piling. Above the weld line the iron was relatively clean with no apparent banding. There was a line of inclusions running across the section near the top of the knife back in the middle of the groove.

In the etched condition (Figure 11) the knife back was mostly ferritic iron (uHv=156, Hv=168) with some carbon present giving areas of ferrite plus pearlite (uHv=133) and pearlite (uHv=159, Hv=157). The grain size ranged between ASTMS 4 - 6. Within the largest area of pearlite there was a ferritic/phosphoric band (uHv=181). There had been carbon diffusion across the weld line. The cutting edge was a slack quenched medium carbon steel with a pearlite plus grain boundary ferrite structure below the weld line (uhv=342), and tempered martensite at the tip (uHv=689, Hv=677). There was no evidence of piling as suggested by the slag inclusions in the unetched condition.

Knife 169/1617 was butt welded Type 2 knife of good quality, utilising quality irons (ferritic iron and steel) and good craftsmanship.

7 KNIFE 169/2502

Knife 169/2502 was ascribed to Type C. It was 100mm long with a maximum height of 13mm. It was complete but had been slightly bent in antiquity and was corroded. X-Radiography showed that the tip has suffered the most corrosion and the full lengh of the cutting edge was also effected. There was a distinct weld line (Figure 12), which was severely corroded for part of its length. The cutting edge longditudinal profile (from the tang to the tip) had a slight concave shape, probably resulting from wear.

A single section was removed from the cutting edge (Figure 12). In the unetched condition two transverse weld lines were visible. They divided the section into thirds, the upper weld was slightly curved. There was also a diagonal band of corrosion across the cutting edge (the lowest third of the section). In the etched condition (Figure 13) the section displayed a carbon profile from the tip to the top of the section. The upper third contained the lowest carbon content and had a bainitic structure. It was divided from the central third by a white/yellow weld line. This part had a tempered martensitic structure with grain boundary pearlite and fine nodular pearlite present. A white weld line divided the mid-section from the cutting edge, which had a tempered martensitic structure. There was a carbon gradient from the knife surface (higher carbon) towards the centre of the knife.

The hardness values obtained for each third of the section are given in Table 5. These show a steady decline from the tip, which reflects the reduction in carbon content and the change in microstructure.

TABLE 5 KNIFE 169/2502 HARDNESS VALUES

	uHv	Hv
Upper Third		
Bainite	243	262
"	273	
Middle Third		
Tempered Martensite	498	460
Grain Boundary Pearlite	383	
Cutting Edge Third		
Tempered Martensite (centre)	649	593
" " (edge)	572	

Knife 169/2502 was of Type 2 manufacture. The presence of two transverse weld lines may be the result of a re-edging of the knife. The upper third being the original knife back, but was carburised due to the subsequent welding and heat treatments. The carburisation is also indicative of the use of ferritic iron rather than phosphoric iron. The knife was manufactured to a high standard.

8 KNIFE 169/2516

Knife 169/2516 was ascribed to Type D. It was 97mm long with a maximum height of 15mm. The X-radiographs showed extensive corrosion of part of the knife back (Figure 14), which ended in an abrupt line and was assumed to indicate a weld line. Above the weld line the corrosion pattern showed the typical fibrous effect of phosphoric/ferritic iron. At the cutting edge the spotted steel pattern was present. This appeared to confirm the presence of a weld line. There was some severe corrosion across the whole blade near the tip which showed the fibrous corrosion extending below the assumed cut-off point suggested by the large area of corrosion on the knife back.

A single section of the cutting edge was removed, (Figure 14). In the unetched condition there were two off-vertical slag lines, i.e. running in a diagonal line up the section, starting at the tip and emerging at the side of the section below the top. There were also other finer slag lines that followed the same trend. This indicated either a heavily piled structure or a knife of Type 1 manufacture. In the etched condition (Figure 15) the overall impression was of a banded structure with alternating bands of ferrite (uHv=183, Hv=152) and ferrite plus pearlite. Some of the ferrite might have been phosphoric. The ferrite grain size was very small (ASTMS 7 - 8) due to the working of the piled structure. There were two areas of higher carbon content. The first was at the top of the section at the edge of the knife and was a short band of pearlite (uHv=297). The second area formed the cutting edge and was the tip of the central band formed by the two major slag lines. At the tip it had a tempered martensitic structure (uHv=488, Hv=345), which degraded to pearlite away from the tip. This edge did not appear to have been formed by a separate piece of steel, but appeared to be part of the central strip. It seems unlikely that it was fortuitous that the highest carbon area formed the cutting edge. It is therefore possible that the knife was manufactured from piled iron and subsequently the cutting edge being carburised, but that other part(s) of the knife became exposed to the carburising medium giving rise to the enhanced carbon content of the edge of the knife at the top of the section.

OTHER EDGED TOOLS

9 BILLHOOK 31/92

The billhook measured 305mm in length and had a maximum width of 44mm. The tip-end was curved round to form a flat hook shape, but the actual end was missing. The tang-end was forged into a half-socket and had a rivet hole to hold the shaft (Figure 16). X-Radiography did not distinguish any structure except a weld or corrosion path on the back of the blade.

Two sections were removed, from the back and from the cutting edge, owing to the size of the object the sections could not overlap. In the unetched condition both sections displayed similar slag distributions, vertically orientated lines of single or dual phase inclusions. In the etched condition the overall structure was of a banded structure. In the back section there were two main bands, ferrite plus grain boundary pearlite, and a band of darker etching ferrite with areas of ferrite plus pearlite. The first area was characterised by the presence of numerous small etch pits. The ferrite plus pearlite and the darker etching ferrite had similar grain sizes (ASTMS 5 - 6). In the cutting edge section there was more banding, which was orientated at a slight angle to the vertical. One band was the darker etching ferrite, the other bands showed variation in carbon contents and quench products. At the tip the structures were martensitic, which degraded to bainites and pearlite away from the tip. The hardness values reflect these changes and are given in Table 6.

The billhook was manufactured from piled irons which included steel (of varying carbon content) and ferritic iron. It had been slack quenched to produce an effective cutting edge.

There was no evidence for the deliberate introduction of a cutting edge. This was formed by the homogenisation of the bands at the cutting edge, for this to be satisfactory phosphoric iron, which inhibits carbon diffusion, had to be avoided.

TABLE 6 BILLHOOK 31/92 HARDNESS VALUES

	uHv	Hv
Back Section		
Ferrite plus (some) Pearlite	173	166
Dark Etching Ferrite	133	123
Dark Etching Ferrite Plus Pearlite	146	
Cutting Edge Section		
Pearlite plus Grain Boundary Ferrite	237	
Pearlite plus Ferrite	172	
Tempered Martensite/Bainite	413	349
Tempered Martensite	446	412

10 COLD CHISEL(?) 169/1045

The tool was similar in form to a modern cold chisel. It was 18mm long and had a diameter of 20mm. It had a rounded square cross-section. A section was cut from the 'cutting edge' which was totally corroded, and therefore, a second one was cut from the head of the tool.

In the unetched condition the head section showed the effect of slight surface corrosion. There were few slag inclusions present and only one slag line which ran through the section for a few millimetres. In the etched condition the head was manufactured wholly from steel, there was some banding indicative of variations in carbon content. The structure was pearlite plus grain boundary ferrite or cementite. In some areas the grain boundary phase had a widmanstatten appearance. The 'cutting edge' section, despite being totally corroded still retained the grain boundary phase, showing as a grain boundary network. The pearlite within the austenite grains had converted to corrosion products. The microstructure of the corroded cutting edge and the un-corroded head are compared in Plates 2 and 3. The corrosion resistance of the grain boundary phase indicates that it was cementite rather than ferrite. Therefore the tool was manufactured wholly from hyper-eutectoid steel. The mean hardness values of the pearlite were:

uHv = 358

Hv = 306

The tool was of very high quality, utilising a large quantity of steel (approximate weight 000gms). Its strength derived from its pearlitic structure, but it had not been quenched to produce a hard cutting edge, which would have been brittle, and would not have withstood repeated hammer blows.

11 CHISEL 169/1858

Tool 169/1858 was described as a chisel. It was similar to a masons chisel, with a wide flat cutting edge.

A single section was removed from the cutting edge. In the unetched condition vertically orientated lines of slag inclusions were observed. In the etched condition it showed the bands to be predominantly ferritic or low phosphorus iron, but there were also thin bands of ferrite plus pearlite, some of which were very thin bands (1 grain) associated with the slag lines. At the top of the section the ferrite had grain sizes ASTMS 4 - 5, and the ferrite plus pearlite ASTMS 5 - 6. This indicates that the carbon diffused into the iron during the working of the iron which resulted in the piled structure. At the tip the carbide became concentrated at the grain boundaries, and tended towards spherodisation. There was no evidence of cold work at the tip, and therefore it is possible that the chisel was used for cutting hot metal. At the tip the grain size was reduced to ASTMS 7 - 8. The hardness values (Table 7) show no significant change between the top of the section and the tip.

TABLE 7 CHISEL 169/1858 HARDNESS VALUES

	uHv	Hv
Shaft		
Small Grained Ferrite	188	
Ferrite	222	146
Ferrite+Pearlite at Weld Line	188	
Ferrite + Pearlite	216	
Small Grained Ferrite	197	
Ferrite (age hardened)	199	
Ferrite	135	
Tip		
Ferrite + Globular Carbide	198	] 169
" " " (low C%)	199	

The piled structure with low carbon steel as harder bands would have made a successful tool

12 <u>AXE</u> <u>24/22</u>

The axe was described as a wood-working tool. X-Radiographs indicated that there was a possible weld joining the haft to the head. The axe was heavily corroded in parts, the corrosion pattern being steel rather than the fibrous 'wrought iron' type (Figure 17). A single section was removed from the cutting edge. In the unetched condition a central slag line was apparent with evidence of slag banding on either side. Etching showed the axe-head to have been manufactured from piled or banded iron folded together and welded down the centre of the section. Associated with the central weld line was a carburised region, which at the cutting edge was tempered martensite, but rapidly degraded to pearlite. On either side of the central weld the banding comprised alternate layers of ferritic/phosphoric iron and ferritic/phosphoric iron plus grain boundary pearlite. The bands varied in thickness and grain size, those with pearlite being thinner than the phosphoric/ferritic iron bands. The hardness (and grain size) of the bands is given in Table 8, at the cutting edge the bands were compressed and had similar hardness values (except the central steel/weld line band). Away from the cutting edge the ferritic/phosphoric bands were harder than the ferrite plus pearlite band. The banding and the hardness values indicate that the clean bands were phosphoric rather than ferritic.

The axe was manufactured in a similar manner to the chisel 169/1858, using piled or banded irons. The axe had been hardened by quenching (as evidenced by the central steel band), but the absence of a large steel cutting edge component meant that this treatment had been inefective. The overall hardness of the cutting edge was low, and therefore the axe would not have been an efficient tool.

TABLE 8 AXE 24/22 HARDNESS AND GRAIN SIZE VALUES

Section Top	uHv	Hv	ASTM
Ferritic/Phosphoric Iron	195	158	>1
" " "	206	-	-
Ferrite + Grain Boundary Pearlite	168	169	5-6
Cutting Edge			
Ferritic/Phosphoric Iron	213	197	2-3
Ferrite + Grain Boundary Pearlite	215	-	5-6
Tempered Martensite	464	-	-

18 CONCLUSIONS

The analyses of the knives confirm the result obtained in the previous metallurgical study and X-radiography examination that the common method of knife mmanufacture was Type 2, i.e. cutting edges butt welded to the knife back. There were two exceptions, Knife 31/340 was of all-steel manufacture, and Knife 169/2516 was of indeterminate manufacture. In general the overall quality was high, although there were several exceptions, in particular Knife 31/663.

Three of the tools had been manufactured from piled or banded iron. Therefore, the cutting edges were not very good quality, although in one case, the artefact had been heat treated. The exceptional tool was the Chisel 169/1045, because it was manufactured wholly from steel. This would suggest that steel was widely available, and not in short supply.

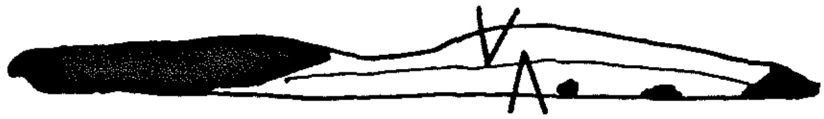

FIGURE 1 KNIFE 31/340 INTERPRETATION OF X-RADIOGRAPHS (X1)

FIGURE 2 KNIFE 31/663 INTERPRETATION OF X-RADIOGRAPHS (X1)

FIGURE 3 KNIFE 31/663 INTERPRETATION OF CROSS-SECTION (X5)

FIGURE 4 KNIFE 169/417 INTERPRETATION OF X-RADIOGRAPHS (X1)

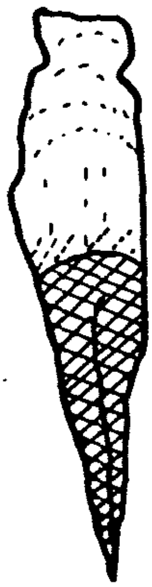

FIGURE 5 KNIFE 169/417 INTERPRETATION OF CROSS-SECTION (X5)

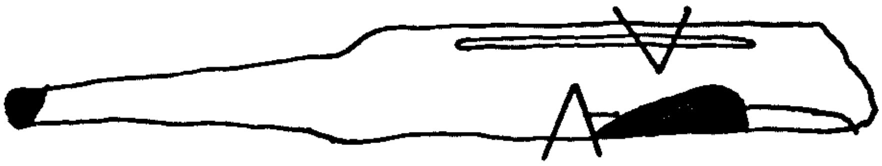

FIGURE 6 KNIFE 169/540 INTERPRETATION OF X-RADIOGRAPHS (X1)

FIGURE 7 KNIFE 169/540 INTERPRETATION OF CROSS-SECTION (X5)

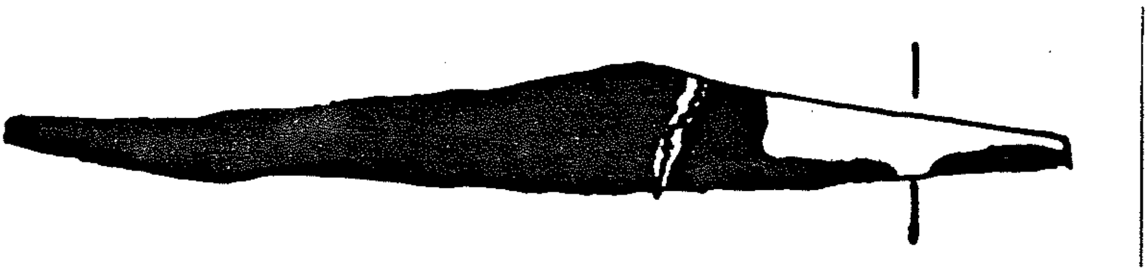

FIGURE 8 KNIFE 169/558 INTERPRETATION OF X-RADIOGRAPHS (X1)

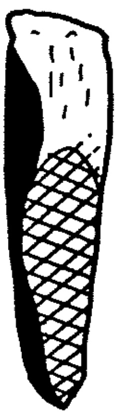

FIGURE 9 KNIFE 169/558 INTERPRETATION OF CROSS-SECTION (X5)

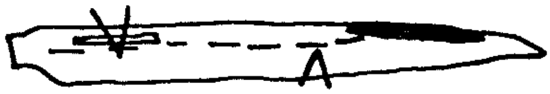

FIGURE 10 KNIFE 169/1617 INTERPRETATION OF X-RADIOGRAPHS (X1)

FIGURE 11 KNIFE 169/1617 INTERPRETATION OF CROSS-SECTION (X5)

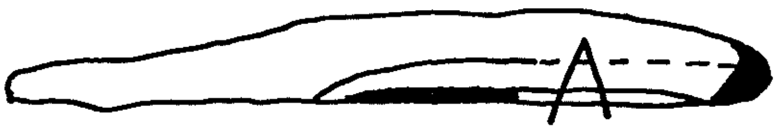

FIGURE 12 KNIFE 169/2502 INTERPRETATION OF X-RADIOGRAPHS (X1)

FIGURE 13 KNIFE 169/2502 INTERPRETATION OF CROSS-SECTION (X5)

FIGURE 14 KNIFE 169/2516 INTERPRETATION OF X-RADIOGRAPHS (X1)

FIGURE 15 KNIFE 169/2516 INTERPRETATION OF CROSS-SECTION (X5)

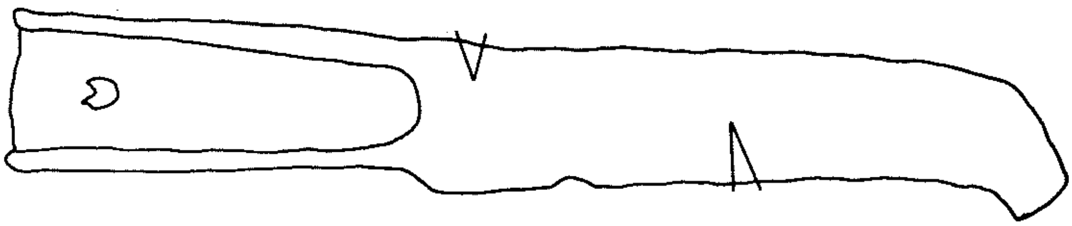

FIGURE 16 BILLHOOK 31/92 INTERPRETATION OF X-RADIOGRAPHS (X0.5)

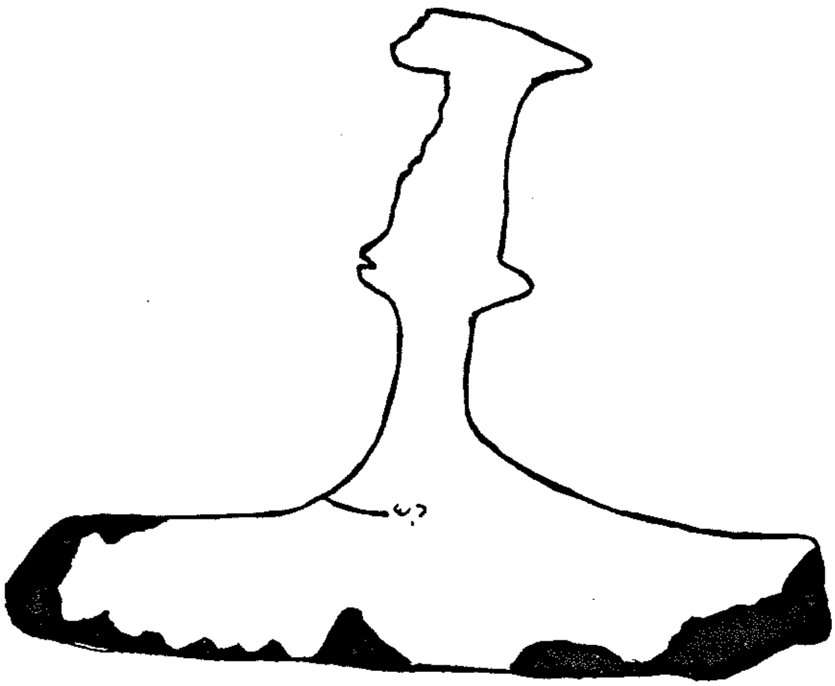

FIGURE 17 AXE 24/22 INTERPRETATION OF X-RADIOGRAPHS (X0.5)

PLATE 1 KNIFE 31/663 FERRITE(?) GRAINS PLUS NETWORK STRUCTURE (X27)

PLATE 2 CHISEL 169/1045 CORRODED CUTTING EDGE SHOWING CEMENTITE GRAIN BOUNDARY NETWORK AROUND CORRODED GRAINS. NOTE ON THE LEFT OF THE PICTURE THE NETWORK IS CORRODED, AND ON THE RIGHT IT IS PRESERVED. (X168)

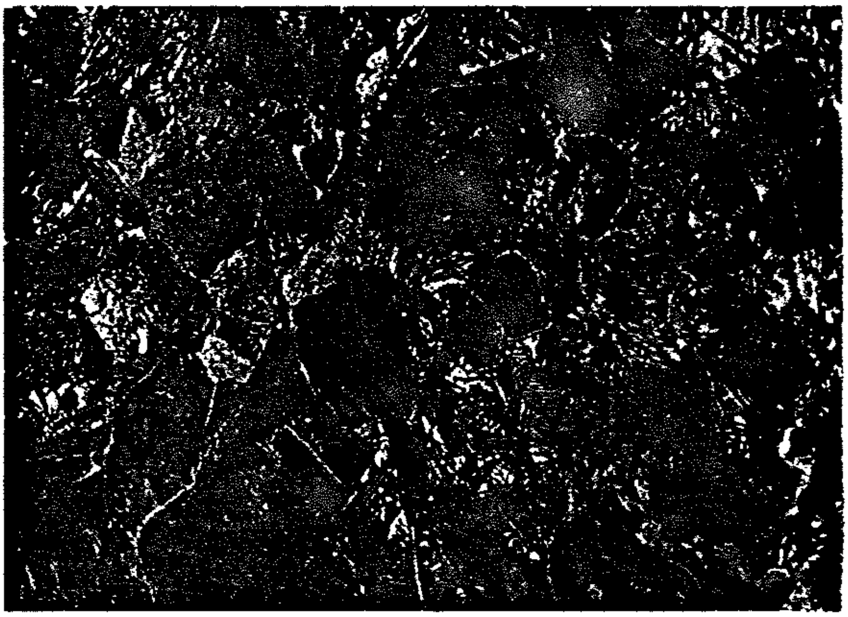

PLATE 3 CHISEL 169/1045. HEAD OF CHISEL SHOWING COARSE PEARLITE GRAINS WITH PROEUTECTOID CEMENTITE. (X420)